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REVIEW OF WORLD ENGINEERING PROGRESS

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IN THIS ISSUE

THE production of high-class work in many machine tools depends on the engineer's knowledge of change gear problems; nevertheless, the problems involved in change gears are not treated in the literature as they deserve.

A method of calculation, with the aid of graphs, is evolved in a treatise on "Change Wheel Gearing," the first instalment of which is published in this issue on page 7. This method simplifies determination of the best result obtainable by a given set of change gears. It also shows how to determine the error involved, without the necessity of evaluating ratios, and the method can be applied if limits of the errors are predetermined.

It frequently happens that after spending considerable time on computation, the resulting gear train cannot be mounted; the treatise proves that a few additional considerations in computation prevent such disappointments.

Disregarding the rules of strength hardly ever results in breakage of the teeth. Nevertheless, this point should be borne in mind, as worn teeth influence the exactness of the result, and it will be shown that the forces to be transmitted by the teeth of change gears can be minimized in quite a simple manner.

If, in addition to providing the required ratio between the speeds of two shafts, the change gears serve for indexing when cutting multiple threads, then even further considerations are involved in computation; this problem will likewise be treated, but on a broader basis than usual.

* * *

It has been observed by several investigators that aerosols may be rapidly agglomerated by intense high-frequency sound waves. The recent development of powerful sound generators opens the way for industrial utilisation of this effect as another means of removing suspended matter from smoke and fumes. The forces acting to cause sonic agglomeration are complex. The more important factors seem to be a combination of the following: (1) co-vibration of particles in a vibrating gas; (2) attractive and repulsive hydrodynamic forces between neighbouring particles; and (3) radiation pressure.

Although this development has been briefly referred to previously in these pages (see *The Engineers' Digest*, July, 1949, p. 241) we thought it to be of sufficient importance to deserve a report of greater length. The article "Precipitation of Smoke, Fog, or Dust Particles by Sonic Waves" on page 14 in this issue has been condensed from two recent American articles. One of these deals with theoretical aspects, whilst in the other examples are presented of installations used industrially to collect sulphuric acid fog, as well as soda ash from the recovery boiler of a paper mill. Evaluation is made of the characteristics of those particular types of industrial fine particle collection problems which have been found to lend themselves to sonic agglomeration and collection treatment, and illustration is given of the many process industries having collection problems for which sonic collectors may be used.

* * *

In superchargers, the power delivered can easily be calculated from volume and head measurements, but it is difficult to ascertain the power input. This can be calculated by torque measurement with a dynamometer and speed measurement. However, the very high shaft speeds for the supercharger require step-up gearing between the driving motor and the supercharger, in which case the torque is measured at the low-speed end and thus includes gear losses. Quantitative determination of the gear losses is possible but the methods are awkward and laborious, and for this reason the Germans have developed a measuring device for the direct measurement on the supercharger shaft of power, torque, and speed. This device is described on page 13.

* * *

The exploitation of the Zisterdorf oil fields during the past decade has strongly stimulated interest in Austria in the development of oil firing systems for various purposes. This interest has been still further increased by the results of the latest geological surveys, which indicated that the Zisterdorf district is probably only a small outlying area near oil fields of much greater capacity.

The types of oil burners developed in Austria are described in the article "Oil burners with Integral Vapour Atomisation Systems," and this article will be concluded next month.

It is realised in Austria that there may be markets for their oil burners in hard currency countries, especially the United States, where approximately 3 million burners of various sizes are being manufactured annually.

CZECHOSLOVAKIA

The Evaluation of the Reliability of Electric Power Supply in High-Voltage Networks

By O. PILAŘ. (From the *Elektrotechnický Obzor*, Vol. 38, No. 16, August 25, pp. 404-408, 6 illustrations.)

THE principles for the evaluation of the reliability of networks are based on observation and study of disturbances in the power supply and restoration of the service. The ratio of the shutdown time of the network to its time of service is a measure of the reliability. This ratio is the disturbance figure S_r, which is given in per mil by the equation :—

$$S_r = \frac{u_r}{8760 - u_r} 1000 \quad .. \quad .. \quad (1)$$

where u_r is the total shutdown time for all consumers in the course of one year as a result of disturbances in the network. This figure relates only to time losses in the system, and does not take into account the magnitude of the load when the interruption occurs. The time u_r partly depends on the design and operation of the system; weather conditions, however, are the main source of disturbance. If S_r is the average disturbance figure obtained from observations over several years, then the ratio S_r/S_r indicates the quality of the service in a particular year.

The disturbance index is another measure of the reliability, and is calculated as follows :—The number of substations R_p which will be interrupted in a year is given by the equation :—

$$R_p = P P_4 \quad .. \quad .. \quad .. \quad .. \quad (2)$$

where P is the product of the length of the lines D and the average number of disturbances d on 1 km of line during the year, i.e., the total number of disturbances, and P_4 is the average number of substations, the services of which are interrupted by one disturbance, and is calculated from eq. (3) as follows :—

$$P_4 = \frac{R_m}{Hh} \quad .. \quad .. \quad .. \quad (3)$$

where R_m is the total number of substations of the network, H the number of automatically operating sections, and h a statistical coefficient. This coefficient depends on several factors, one of these being that the average time of interruption of manually operated sections is greater than that of the automatic sections, another being that one disturbance often interrupts several sections.

The average number of disturbances in the network of the Moravian Electricity Authority is 0·35/km/year. The coefficient h depends on H and is plotted in Fig. 1 against H as abscissae.

By dividing eq. (2) by R_m, the number of substations, the relative yearly number of disturbances per substation, P_{1r}, is obtained :

$$P_{1r} = \frac{R_p}{R_m} = \frac{Dd}{Hh} \quad .. \quad .. \quad (4)$$

By comparing the relative number of disturbances in a particular year per substation with that established by the Electricity Authority, the disturbance index p is obtained. This index averaged 1·08 in Moravia for the years 1931-48.

The duration of all disturbances is obtained by multiplying the number of disturbances with the average time of one disturbance.

The time of a disturbance consists of two parts, of the time taken in locating and sectionalizing the disturbance and the time taken in restoring the service. The average time P_6 of a disturbance is

$$P_6 = \frac{\Sigma(T_p)}{R_p} = \frac{\Sigma(T_2) + \Sigma(T_5)}{R_2 + R_5} \quad .. \quad .. \quad (5)$$

where T_p is the duration of a disturbance.

The disturbances can be divided into those of long duration (P_2 R_2, T_2) and those of short duration (P_5 R_5, T_5), with an average time of 5 minutes for the latter, after which the service is automatically restored.

The average time of a disturbance P_6 depends on the relative occurrence of faults of short and long duration. Short-duration faults are eliminated by the automatic action of the switchgear and often go unnoticed by the consumer. The duration of long disturbances depends on the speed of location of the fault, the magnitude of the fault, and the efficiency of the maintenance personnel.

The average time of a disturbance P_6 has been found to be 0·5 hour. The ratio of the time of a particular disturbance to the average time of a disturbance is the coefficient t. The reciprocal of t, $1/t = r$, is the coefficient of the speed of restoration of the service. Fig. 2 shows the variation of p, r, and P_5 during the years 1931-1948 in the Moravian network.

According to the previous definitions, the total shutdown time for all consumers is

$$u_r = 0{\cdot}5\, t\, P_{1r}\, p \quad .. \quad .. \quad (6)$$

The relative time loss in the power supply

$$u_r = 0{\cdot}5\, t\, P_{1r} \quad .. \quad .. \quad .. \quad (7)$$

and the assumed time loss in the power supply

$$u_n = 0{\cdot}5\, P_{1r} \quad .. \quad .. \quad .. \quad (8)$$

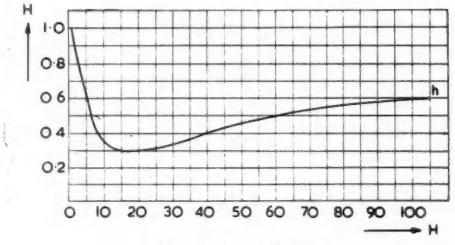


Fig. 1. **The coefficient h.**

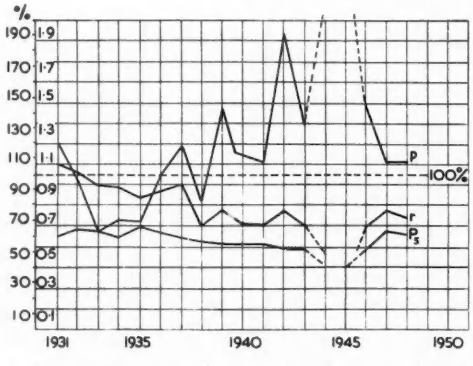


Fig 2. **The coefficients p, r, and P_5 in the years 1931-1948 in the network of the Moravian Electricity Authority.**

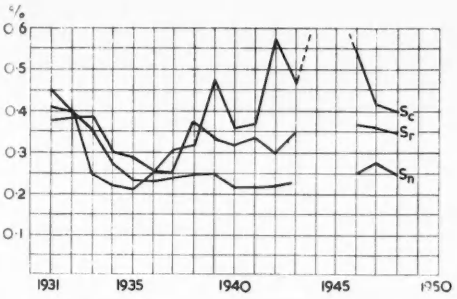


Fig. 3. **The figures of disturbance in the years 1931-1948.**

The disturbance figures corresponding to u_r and u_n are represented by S_r and S_n.

The variation of S_c, S_r and S_n during the years 1931-1948 is shown in Fig. 3. As stated previously, these figures only give the shutdown times. In Fig. 4, however, the curves show the yearly quantity of undelivered power in kWh per 1 km of high-voltage line in Moravia due to disturbances. This value decreased until 1937, then rose to its peak during the occupation.

The Moravian Electricity Authorities determined average values of their disturbance figures, the disturbance index, the number of disturbances per km of line, the duration of a disturbance, and the power

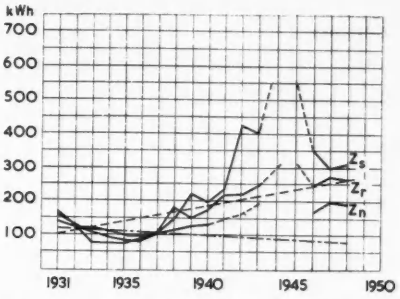


Fig. 4. **Power not delivered per km of line.**

Z_s = Effective kWh not delivered per 1 km of line
Z_r = Relative kWh not delivered per 1 km of line
Z_n = Assumed kWh not delivered per 1 km of line
$Z = Z_s D = Z_r p D = Z_n t p D$

not delivered per km line as a result of disturbances, etc. These figures are compared regularly with the actual figures evaluated from the disturbances of a particular year.

These evaluations present a good picture of the service, but they cannot be applied in this form to networks without transformer substations. The figures do not account for changes in the power consumption and the differences in the power supplied by the different substations.

AUSTRIA

Oil Burners with Integral Vapour Atomisation Systems

By O. Dancsecs. (From *Maschinenbau und Wärmewirtschaft*, Vol. 4, Nos. 10 and 11, October and November, 1949, pp. 155-159 and 171-176, 11 illustrations.)

The exploitation of the Zisterdorf oil fields during the past decade has strongly stimulated interest in Austria in the development of oil firing systems for various purposes. This interest has been still further increased by the results of the latest geological surveys, which indicated that the Zisterdorf district is probably only a small outlying area near oil fields of much greater capacity.

Five main types of oil burners have been developed: (1) Fuel atomiser burners; (2) Burners with additional vapour or air atomisation; (3) Emulsion type burners, in which the oil is mixed with air into a foam; (4) Pressure burners; (5) Rotary burners with centrifugal atomisation.

The principle of vapour atomisation was the first to be widely used, because it is simple and sturdy, and can take any grade of oil. The burner can be designed for manual control, fully automatic control, or semi-automatic operation (manual starting and automatic shut-down).

The oil burner with vapour atomisation was introduced in Austria by engineers who returned from Russia after the first World War, and burners of this type were at first chiefly used in the baking industry.

The first designs consisted mainly of a spiral tube, built integral with the burner, the water flowing through this coil being evaporated by the heat developed by the burner itself. The tubes soon burned through, however, owing to water deposits causing heat concentration at certain points. These rather primitive systems were subsequently superseded by electrically operated burners, i.e., air atomisers or pressure burners.

In more recent years, burners with integral vapour atomisation systems have been sucessfully developed for industrial purposes and central heating. These burners are also extensively employed in drying ovens, hot air generators, air drying equipment, kitchen boilers, vulcanising, distillating, and sterilising equipment, hot water systems, high-pressure boilers, etc.

The use of these burners has become even more widespread since 1945, owing to the present shortage of electric power. The original spiral tube has now been replaced by a small vapour generator similar to that of a flue boiler. The "Simplex" burner, first produced in 1927, has been widely used in many countries; since then the "Autark" and the "Berot" burner have also become popular. Towards 1937, the "Olympia" burner was put on the market by Fordham & Co., of Vienna, and the "Rekord" burner was developed for small size installations.

GENERAL FEATURES

The main advantages of the burner with an integral vapour atomisation system are: (1) No electricity is required; (2) Any type of heating oil can be employed; (3) A more gentle treatment of the heating surfaces is ensured, owing to the soft flame used; (4) Highly adaptable regulation is obtained by altering the flame intensity.

Its drawbacks are the fairly long heating-up time of 10-25 minutes required, the noise generated, and the amount of servicing required owing to the formation of water deposits.

Additional advantages are: (5) Maximum flame power for the space available; (6) Extremely low air consumption: (7) A reliable and steady flame; (8) Practically complete combustion by controlling the quantities of oil, air, and vapour used; (9) Reliable and simple design; (10) Moderate sales price.

The water supply is from a pressure head of 2-5 atmospheres (about 30-70 psig) obtained either from the mains or from a small tank situated at a higher level. The water is evaporated in a vapour generator by the radiant heat and the heat due to direct contact of the oil flame. The oil is atomised at a vapour pressure of 1-3 atm. gauge (15-45 psig), a pressure of 1·5 atm (22 psig) normally being used. For warming up, an auxiliary firing system is provided, which uses wood, charcoal, liquid fuels such as petrol, gas oil, and heating oil, or town gas. When stationary conditions are reached, the oil burner takes over the work of this auxiliary system. The change-over can then either be made by hand or be dispensed with if a complete cut-off of the auxiliary system is not considered necessary.

An oil tank, situated about 1·5 metres (5 ft) over the centre of the burner and in front of the oil atomiser, supplies the oil to the burner. An automatic feed system ensures that the water in the vapour generator is maintained at a constant level.

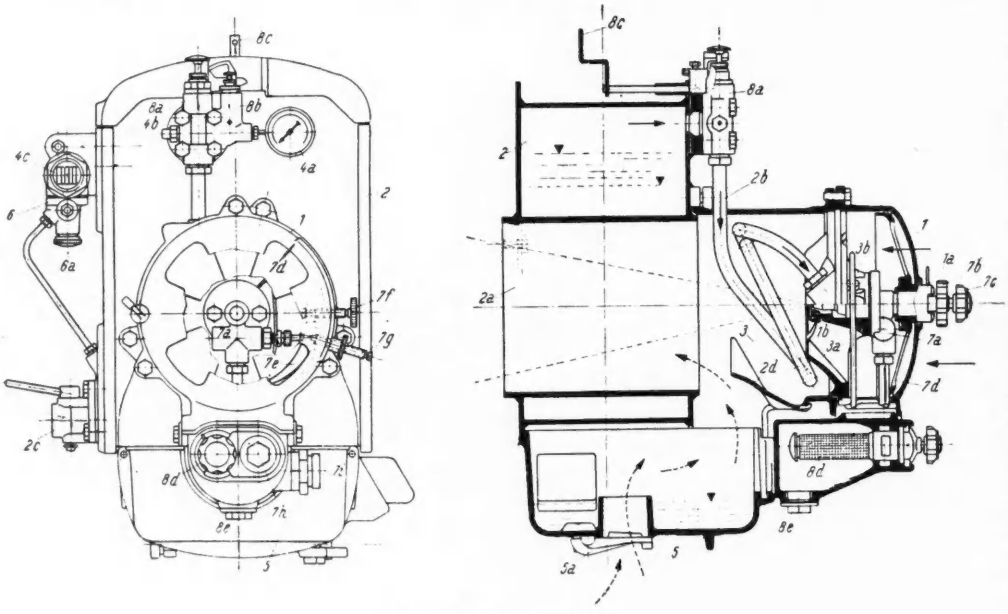


Fig. 1. **The "Autark" burner.**

1 burner head.
1a burner.
1b nozzle ring.
2 vapour generator.
2a fire tube.
2b superheater spiral.
2c drain valve.
2d flame screen protecting the superheater tube during heating-up.
3 mixing chamber.
3a injector cone with guide vanes.
3b air ducts.
4a pressure gauge.
4b spring-loaded safety valve.
4c water gauge.
5 heating-up system.
5a air flap, open during heating-up only.
6 feeder head.
6a water inlet.
7a piston-controlled oil valve.
7b jacket vapour control.
7c oil nozzle needle adjustment.
7d rosette type air draught regulator.
7e sliding shutter.
7f sliding shutter adjustment.
7g angular adjustment of sliding vanes.
7h vapour-controlled oil valve.
7i oil inlet.
8a minimum vapour-pressure valve.
8b fire protection valve.
8c lever for fire cord.
8d fine oil filter.
8e cleaning plug.

DESIGN DETAILS

The main components which will be described in this section are (1) the burner head; (2) the vapour generator; (3) the mixing chamber; (4) the safety devices of the vapour generator; (5) the heating-up equipment; (6) the feeder head; (7) the flame control equipment; and (8) other safety appliances and accessories.

The burner head with the atomiser burner injects the mixture of vapour, oil and air. It is arranged horizontally, at the centre of the fire tube, with one or two ring-shaped nozzles and a central passage. There are two basic arrangements: in the first, the oil flows out through the central passage while the vapour comes through the annulus; in the second, the oil is injected through the inner annular section while a core of vapour is sprayed through the central passage and through the outer annular section. The mixing is mainly due to the vapour from the outer annulus.

The vapour generator is a miniature boiler made of welded boiler sheet, with a strong smooth fire-tube. Generally, an eccentric Cornwall-type arrangement is adopted. A superheater tube, in some cases ring-shaped, is provided to dry and superheat slightly the atomiser vapour to ensure that a good atomisation will be achieved. A hand-operated device at the bottom of this unit is provided for draining and extracting any water deposits.

The mixing chamber, generally cylindrical, also carries the burner head.

The safety devices for the vapour generator comprise a gauge indicating the atomiser pressure, a weight- or spring-loaded safety valve, and a water gauge indicating the water level in the vapour generator.

The heating-up equipment, a well or cup under the mixing chamber or under the vapour generator, is filled with one of the fuels already mentioned; the fuel is then ignited with a taper.

The feeder head has a built-in or externally arranged non-return valve, and a built-in feed valve which is controlled by a float situated in the vapour generator or in a vessel communicating with it. In some designs a hand-operated feed valve is also provided. These feed valves are arranged in such a way that they will remain as cold as possible to avoid scale formation;

scaling occurs at temperatures as low as 60-70 C.

The flame control equipment serves to adjust the burner output to obtain the amount of heat required, and comprises oil, vapour and air regulating devices. The equipment is operated either manually, or automatically using temperature-sensitive pick-ups such as thermostats, pressure diaphragms, or Samson regulators. Regulation of all three media is not provided in all designs. When multiple regulation is used, the control devices can be interlocked to obtain optimum adjustment.

The safety appliances and accessories also include:

(a) an automatic cut-off for the burner, operating when the pressure is lower than the minimum vapour pressure of 0·8-1·0 atm. gauge (12-14·7 psig). In case of a failure of the vapour supply, this also prevents oil flow and possible explosions:
(b) automatic simultaneous cut-offs for both the burner and the oil supply in the event of a supply failure or when superheated vapour is formed in the vapour generator;
(c) fire protection equipment cutting out the burners when a fire occurs in the vicinity;
(d) fine-mesh strainers for the removal of impurities from the oil.

Generally, the fire tube of the vapour generator is connected to a short fire-brick channel to obtain more intensive combustion owing to the re-radiated heat which has the effect of shortening and stabilising the flame.

The feed system has been the subject of considerable development work, and in modern designs this problem has been solved satisfactorily. The new burners are capable of working with a soft flame on heavy oils.

DESCRIPTION OF VARIOUS TYPES OF BURNERS

This section gives a review of various Austrian burner designs, listed alphabetically according to the trade names given by their manufacturers.

A. The "Autark" Burner.

Manufacturers: "Unitherm," Österreichische Ges. f. Universelle Wärmetechnik m.b.H., Vienna.

This burner was specially designed to obtain a high flame output per cubic inch, with a very low excess air ratio and a moderate vapour consumption. Practically complete combustion is also claimed to be obtained by suitable control of the oil, air and vapour in the mixture. The system is easily regulated. Two types of burner are produced:

Type 25/2: oil consumption 8-30 kg/hr.
Type 50/3: „ „ 20-70 kg/hr.

The vapour regulation is incorporated in the atomiser-burner. The vapour is injected both centrally and through an outer annulus, the oil being sprayed between the two vapour spaces. A screw is provided for initial adjustment of the flow cross-section of the core vapour according to the size of the furnace, when the burner is being installed. The outer annulus is formed by a cover over the burner shaft and the oil nozzle ring. The jacket vapour is controlled in a manual system by a handwheel, or in a semi-automatic system by means of a rosette-type draught regulator operated by the rotation and axial displacement of a threaded shaft connected to the burner. Tangential slots are used to give a turbulent motion to the jacket vapour.

The oil spray from the annular nozzles is seized by the two streams of vapour flowing in opposite directions, while air is also drawn in through a system of guide vanes which imparts to it a strong rotary motion. According to the nozzle adjustment used, a long, weak and luminous flame, or a short, broad flame with intensive high temperature radiation, can be obtained, which, owing to the rapid decomposition of the heavy hydrocarbons in its tip, is similar in character to a gas flame.

Oil regulation is by means of a piston valve kept open by spring tension. The valve is controlled by one of the sliding shutters connected to the rosette type air draught regulator, which applies pressure on the valve and tends to close it to a certain extent. The oil spray is thus controlled by the amount of air allowed to flow through, and the sliding shutter can be initially adjusted with the aid of a screw to take care of heating oils of different viscosities.

Air regulation is achieved by means of a rosette disc with four slots. The rosette can be either adjusted to a fixed setting, or regulated by automatic controls via a system of chains or belts. The fresh air aspirated by the burner first passes through a set of guide vanes giving it a rotary motion, and is then injected into the atomiser vapour. When the system is required to operate under overload conditions, secondary air can also be used by opening the slots provided at the bottom of the burner.

The air, oil and vapour control systems are interconnected in order to obtain correct relative adjustment under various operating conditions.

The vapour generator has a capacity of 6 or 10 litres, according to the size of burner used. The superheater spiral is in the mixing chamber of the burner. The spring-loaded safety valve is made in one block with the fire-protection valve.

The heating-up system is a tub or well with handles for easy removal for cleaning. The well is arranged under the vapour generator and not between this unit and the burner. The arrangement is such that the heater flame is forced to change its direction several times, the object being to obtain a short warming-up period of 8-10 minutes. The system is also provided with a flame screen which protects the burner nozzles and the control devices against excessive temperatures and thermal distortion.

The feeder head of the water supply system contains a non-return valve and the feed valve which is controlled by a float in the vapour generator. The feed valve has an adjusting screw with a contact pin. The sealing between the vapour generator and the feed valve space is provided by a metal diaphragm which follows the motion of the valve shaft. Parallel to the non-return valve is a manually-operated feed valve with a threaded spindle and a knob. To avoid water deposits, the feed valves are situated in a low-temperature part of the system. The main feed pipe is a small diameter tube between the feeder head and the drain valve. This valve is designed to allow a plunger actuated by an eccentric to press the valve disc against the valve seat in order to obtain increased contact pressure and a good seal.

The safety apparatus of the oil burner comprises an oil valve, situated under the burner and controlled by the atomiser vapour. This oil valve allows oil to flow through only in the presence of vapour, and this can only occur when vapour flows over the atomiser nozzles, because the vapour control pipe which operates this valve comes directly from the vapour space inside the burner. The other safety devices are:—

1. A spring-loaded minimum vapour-pressure valve. This valve is not self-opening but has to be opened by hand after heatiing up and reaching a vapour pressure of about 1 atmosphere. It then remains open as long as the pressure exceeds 1 atm. gauge. The vapour can then flow to the burner and through the vapour control line to the oil valve. According to whether this valve is open or closed, the vapour pressure acts on different sides of the valve disc. The minimum-pressure valve can also be operated by hand as a safety valve, and its closing also automatically closes the oil valve.
2. The fire protection valve, built in the same unit as the safety valve, is a spring-operated piston-type valve. Normally closed, it is adjustable by means of a screw, and is automatically opened in case of a

fire by the release of a locking device designed as a stepped flap. This flap is spring-loaded and tends to open the valve but its operation is prevented by a safety cord. In the event of a fire in the vicinity of the burner, the string burns and breaks off, and the flap opens the valve so that the vapour is able to flow out into the open. The vapour pressure is then reduced, and this causes the minimum-pressure valve to act on the vapour-controlled oil valve which stops any further flow of oil.

3. A heat-fuse system is also provided. If the water level sinks owing to a failure in the supply, and the temperature in the vapour chamber rises, a fusible plug melts, and this enables the vapour to flow out of the burner. The burner then stops operating as a result of the action of the minimum-pressure valve and the oil valve.
4. A fine-mesh oil strainer is situated in the same block as the vapour-controlled valve. In the latest model, this strainer is inserted into a bayonet type socket. The strainer is arranged close to the burner to ensure that the oil becomes sufficiently fluid during the heating-up period so that the burner may start operating smoothly.

The atomiser vapour is approximately 3 per cent of the quantity of vapour generated by the main boiler fired by the burner, and requires approximately 30 per cent of the total quantity of oil used. This burner gives fully satisfactory operation at part-loads down to approximately 20 per cent of its maximum output.

In conclusion, the main features of this burner are: (1) Simultaneous but independent regulation of oil, vapour and air flows according to the amount of heat required, with favourable combustion conditions achievable at all loads; (2) Specially designed drain valve system with a good seal provided by an eccentrically actuated plunger; thorough mixing of oil, vapour and air, owing to the rotary motion of the atomiser vapour and the primary air; (3) Elimination of secondary air under normal load conditions.

(*To be continued*).

GERMANY

The Introduction of the Candela

(From *Elektrizitätswirtschaft*, Vol. 48, No. 10, October, 1949, p. 251.)

AFTER the introduction of the stable incandescent lamp, when illumination began to spread rapidly, it soon became necessary to establish a primary standard of light which would always be reproducible to specification. It was then that Germany and many other countries introduced the Hefner candle and the English-speaking countries their own standards. The latter were not, however, primary standards in the strict sense of the term, but represented the adopted unit—the International Candle—by means of incandescent lamps operating under exactly defined conditions. Thus, the Hefner and the International candles were widely used side by side, but neither was based on a primary standard which could satisfy present-day requirements.

The first step towards the establishment of a reproducible primary standard on strictly scientific lines was taken—though without this intention—in the realm of pure physics, with the investigation of the radiation from a "black body." For experimental purposes this was represented by a hollow body of a material able to withstand the temperature of molten platinum, in which it could be immersed. The hollow body has a small aperture, through which radiation emanating from the internal surface can emerge. This body was taken as the basis for the primary standard unit of brightness. The whole body is immersed in molten platinum and the brightness of the small aperture is measured at the freezing point of platinum. The brightness measured is, by definition, assigned the value of 60 units of light per square centimetre, because the magnitude of the unit thus derived is very near that of the Hefner and International candles used until now. The freezing point of platinum is always reproducible, which means that a primary standard has, in fact, been found. The unit of light derived from this has been termed the "New Candle," or "Candela" (abbreviated cd), and has been accepted by the International Commission on Illumination.

The measurement of light must take into account the yellowish colour of the black body radiation at the freezing point of platinum. Bodies radiating at higher temperatures, for instance, gas-filled incandescent lamps, have a whiter colour. The human eye cannot with any degree of certainty, judge whether two light sources of different colour are of exactly equal brightness. However, as the human eye is still an essential factor in measurement, the "spectral sensitivity" values had to be introduced. These were derived from the mean data from measurements of the spectral sensitivity of the eyes of a large number of observers, and are generally referred to as the "mean relative spectral sensitivity values in the V_λ-curve."

To determine whether the brightness of light sources of differing colours are equal, filters must be used to approximate the colours. Thus, in the case of yellow colour, a blue glass filter is used, the influence of which can be calculated. If the black body is observed (at the freezing point of platinum, 2042° K) through a blue glass, the colour impression is gained of a black body at 2360° K. A light source of the latter temperature, if viewed through a blue filter, produces the impression of a radiator at 2800° K, for instance, a "Nitra" nitrogen gas-filled lamp. To measure the brightness of such a lamp, the gap between 2042° K and 2800° K must be bridged.

Taking the described measurements as a fundamental basis, national laboratories issue "standard bulbs" of various colours or, as is the generally accepted term, "colour temperatures"; they comprise three groups of incandescent lamps which are correlated, respectively, to the three temperatures mentioned, namely, 2042° K, 2360° K and 2800° K.

Light can be measured photometrically (in lumen), or directly in watts. The ratio of the results of the respective measurements determines the conversion factor of the systems, which *a priori* must be equal to 1. The conversion factor of the adopted units, or the "photometric radiation equivalent," is 680 lm/W.

In the case of the Hefner and the International candles, measurements of lumens as well as watts had to be carried out. In the case of the new unit based on the radiation from a black body, the photometric conversion factor can be calculated. The energy emission of a black body can be calculated from Planck's equation, and the photometric assessment of the emitted energy is determined by definition.

Change Wheel Gearing

By O. LICHTWITZ, M.I.MECH.E.

PREFACE

THE computation of change gears is a particular branch of shop mathematics. Whereas for other purposes solutions are obtained by substituting numerical values for symbols in general formulae, in the case of change gears there are only formulae for a ratio, which must be expressed by the numbers of teeth of available change gears, and suitable numbers must be chosen. Any method of computing change gears, therefore, is a matter of trial and error. The peculiarity of change gears requires a certain sense for numbers which must be acquired by practice; the examples in this series will serve as a guide.

The required ratio must in some cases be expressed exactly, e.g., when cutting standard threads in a lathe, or for the purpose of indexing in gear cutting machines; these cases do not involve serious problems, and may readily be tabulated. In other cases, the ratio can be expressed only approximately, for instance, when cutting helical or bevel gears where trigonometric functions lead to unwieldy ratios. Charts which are supplied for such purposes usually contain only a modest selection of the possible gear combinations, and they may be sufficient for lesser requirements; however, the ambitious engineer who wants to make the best use of his machine must put himself to the trouble of computing gear trains, and the object of this series is to assist him.

Although the expression of a ratio by numbers of teeth is the main task, there are some additional problems, as the gear wheels must be mounted without interference and should be so used that the teeth are not stressed to a higher degree than is necessary. In cutting multiple-start threads in a lathe, the change gears have to serve the additional purpose of indexing. Change gears will be dealt with in this series from all these aspects, and the concluding chapter on the gearing of some typical machine tools should prepare the reader for any practical requirement.

Change gear problems must sometimes be solved by engineers who are not primarily mathematicians, or who have never had an opportunity of becoming familiar with mathematics. Taking this fact into consideration, problems are at times tackled in a form which may be disapproved by mathematicians. Instead of starting with a general case, a particular case will sometimes be considered and the result generalized; some lengthy deductions which might confuse readers not so well versed in mathematics are omitted. It might be expected that the problems would best be solved on a purely arithmetical basis, but actually the use of analytical geometry greatly simplifies the solution. As no more than the most elementary principles of analytical geometry are required, the preparatory Chapter II will make their application possible even by engineers who have not acquired a more thorough knowledge of mathematics.

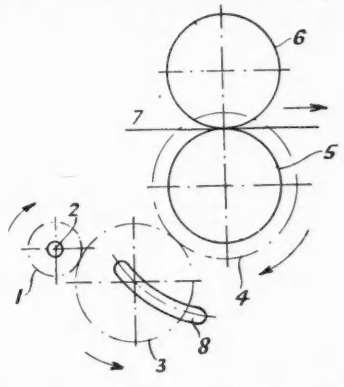


Fig. 1. **Feed mechanism incorporating change gears.**
1—driving gear, 2—main shaft, 3—idler, 4—driven gear, 5—lower feed roller, 6—upper feed roller, 7—metal strip or paper web, 8—slot for the stud.

CHAPTER I

THE NATURE OF CHANGE GEARS

Many machines require a changeable relation between the speeds of two shafts. A well known example is the screw-cutting lathe, where the ratio of the number of revolutions of spindle and lead screw is determined by the pitch of the thread to be cut. A later chapter deals with the gearing of the lathe and some simpler cases can be considered first.

Fig. 1 shows schematically the feed mechanism of a metal or paper working machine. The gear on the main shaft drives the gear on the lower feed roller through the intermediate gear or idler. The upper feed roller can be positively connected with the lower through a pair of gears (not shown).

The amount of stock which is fed per revolution of the main shaft depends on the diameter of the feed rollers, and on the gears. The idler and the driven gear can be assumed to be unchangeable parts of the machine, but there are usually various gears which may be used for the driving gear, and these are variously known as change gears, pick-off gears, and slip gears. Throughout this series they will be referred to as change gears.

The purpose of the idler is to bridge the gap between driving and driven gears, and the position of its stud varies with the driving gear. As the centre distance of idler and driven gear is not changed, it is expedient to provide the slot for the stud in the form of an arc concentric with the driven gear. The idler has no influence on the amount of feed, but influences the direction of rotation.

The driving gear determines the feed, and it is very simple to choose the proper gear.

It is also possible to use a constant driving gear and to change the driven gear. In such case the slot for the stud would be concentric with the driving gear, and the resulting feed is inversely proportional to the number of teeth in the driven gear.

If only one gear is changed, there must be as many gears available as ratios required, and the steps in the possible range are rather coarse. The number of ratios is increased and the steps are reduced if in a two-gear train, or simple gear train, Fig. 2, both the driving and driven gears are changed. This is only the first step, however, and in most cases two pairs of change gears are used (Fig. 3). The next step is obviously to use three pairs of gears (Fig. 4). Six-gear trains involve some difficulties, and are seldom used, but their advantages are unquestionable and it is hoped that their treatment will contribute to a widening of their application.

The reference letters of the gears in Figs. 2 to 4 will be used for indicating quantities, such as the number of teeth, or the pitch radius, which is proportional to the number of teeth.

The ratio of the number of revolutions of driven and driving shaft, in a two-gear train, is a/b, or the speed of the driven shaft is a/b times the speed of the driving shaft. If, for example, $a = 20$ teeth, and $b = 40$ teeth, the driven shaft makes $a/b = 20/40 = \frac{1}{2}$ revolution during 1 revolution of the driving shaft.

In the case of a four-gear train, usually called a compound gear train, the first driven gear is connected with the second driving gear by a common bush, and both run together on a stud. During one revolution of the driving gear, these combined gears make a/b revolutions; similarly, during one revolution of the gears on the stud, the second driven gear makes c/d revolutions. The ratio of the speeds of driven and driving shaft is, therefore, $(a/b) \times (c/d) = ac/bd$, that is, a fraction where the numerator is the product of the driving gears, and the denominator the product of the driven gears.

If the number of teeth is, for example, $a = 25$, $b = 82$, $c = 21$, and $d = 97$, the driven shaft makes $\frac{25 \times 21}{82 \times 97} = \frac{525}{7954}$, or roughly 1/15 revolution during one revolution of the driving shaft. The four-gear train is equivalent to the two-gear train 525/7954; by using small gears, four-gear trains thus offer the same result as the equivalent large gears in two-gear trains. If a ratio of approximately 1/15 were to be obtained by a simple gear train (disregarding worm gearing), either the driving gear would be so small, or the driven gear so large, as to be impractical.

In the case of a six-gear train two studs are used. Similarly as above, the driving shaft makes $a\ c\ e/b\ d\ f$ revolutions during one revolution of the driving shaft. Six-gear trains are identical with simple gear trains with still higher numbers of teeth than in the case of four-gear trains, and enable still greater reductions. The gear train $\frac{30 \times 25 \times 20}{90 \times 100 \times 120}$, for instance, causes a reduction of $1/3 \times 1/4 \times 1/6 = 1/72$.

For the sake of simplicity, only ratios which are less than 1, in other words, only ratios which can be expressed by a proper fraction will be considered in Chapter III. Ratios such as 51/23 are of course possible, and in such case it is advisable to consider the inverse ratio 23/51 for the calculation and to interchange driving and driven gears when they are mounted.

Chapter II

MATHEMATICAL FUNDAMENTALS

Change gear problems are chiefly of a mathematical nature and a certain knowledge of mathematics is necessary, both for the understanding of, and practice in, solving the problems. Some mathematical principles, a knowledge of which will be required in later chapters, are reviewed here, and readers who want more precise explanations are referred to regular textbooks.

(*a*) *Factorising and the Use of the Factor Table*

It has been shown in the previous chapter that a compound gear train is equivalent to a train consisting of two gears with rather high numbers of teeth; when computing compound gear trains, it is, therefore, necessary to consider only numbers which can be broken down into the product of suitable numbers.

The most reliable method of investigating whether a number can be suitably factorised consist in the use of a table of factors, an excellent one being the Factor Table by Dr. George Kaván (Macmillan, 1937), which, unfortunately, is now out of print. Table I is an abridged factor table. It does not contain numbers which are divisible by 2, 3, or 5; such numbers can readily be recognized, and can be divided by the factors indicated. On the other hand, Table I does not contain what in most cases of change gears must be considered as "ballast."

Change gears usually have not more than 100 teeth, although higher numbers are occasionally used (for instance, a gear with 127 teeth when cutting metric threads in a standard lathe); prime numbers beyond 97, therefore, have not been considered. Anticipating a later investigation, six-gear trains, using gears up to 60 teeth, enable similar results to those of four-gear trains, using gears up to 100 teeth; Table I, therefore, terminates with $205379 = 59 \times 59 \times 59$, and comprises:

(1) all products of two numbers up to 97, e.g., $5429 = 61 \times 89$;
(2) all products of three numbers up to 59, e.g., $49979 = 23 \times 41 \times 53$;
(3) products of three numbers which partly exceed 60, but do not exceed 100, within the range of the table, e.g., $56729 = 17 \times 47 \times 71$.

Several numbers can be broken down in several ways, e.g., $7007 = 77 \times 91 = 7 \times 11 \times 91 = 7 \times 13 \times 77 = 11 \times 13 \times 49$; only one possibility is indicated in such cases, as the others are obvious.

Many numbers, such as $46189 = 11 \times 13 \times 17 \times 19$, are not contained in Table I, although they have low-number factors; the reason is that they have more than three factors smaller than 100, and higher than six-gear trains are hardly ever applied.

For the sake of completeness, the rules for identifying the factors 2, 3, and 5 are given as follows.

A number is divisible by 2 if it is even, e.g., $6586 = 2 \times 3293$; the latter number is contained in Table I, and $6586 = 74 \times 89$.

A number is divisible by 3 if the sum of its digits is divisible by 3, e.g., 11409 (with the sum of the digits $1 + 1 + 4 + 0 + 9 = 15$) $= 3 \times 3803$. However, as 3803 is not a suitable number, and is not contained in the table, 11409 is likewise unsuitable.

A number is divisible by 5 if the last digit is either 5 or 0, e.g., $1505 = 3 \times 301$, and consequently $5 \times 7 \times 43 = 35 \times 43$.

If there is a number which is only slightly beyond the range of Table I, one may be tempted to find out whether it is perhaps divisible by one of the next prime numbers 7, 11, or 13. All these three numbers can be investigated by a common operation, due to the fact that $7 \times 11 \times 13 = 1001$; not only 1001, but also multiples of it are divisible by those three prime numbers.

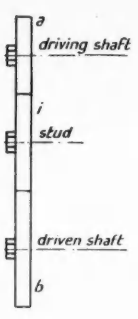


Fig. 2

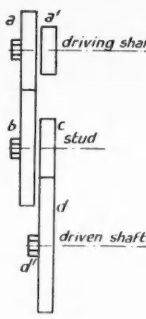


Fig. 3

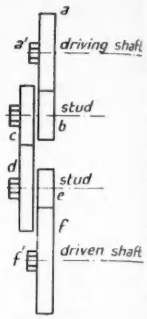


Fig. 4

Fig. 2. **Single or two-gear train.**
a driving gear, *b* driven gear, *i* idler.

Fig. 3. **Compound or four-gear train.**
a first driving gear, *a'* distance piece, *b* first driven gear, *c* second driving gear, *d* second driven gear, *d'* lock nut.

Fig. 4. **Six-gear train.**
a first driving gear, *a'* lock nut on the driving shaft, *b* first driven gear, *c* second driving gear, *d* second driven gear, *e* third driving gear, *f* third driven gear, *f'* lock nut on the driven shaft.

TABLE I. FACTORS FOR COMPUTING FOUR- AND SIX-GEAR TRAINS.

7	1. 7	869	11.79	2233	7.11.29	4171	43.97	6727	7.31.31	10199	7.31.47	14297	17.29.29	18377	17.23.47	22997	13.29.61
11	1.11	871	13.67	2257	37.61	4183	47.89	6851	13.17.31	10241	11.19.49	14329	7.23.89	18389	7.37.71	23023	13.23.77
13	1.13	893	19.47	2261	7.17.19	4187	53.79	6853	7.11.89	10309	13.13.61	14399	11.17.77	18469	11.23.73	23051	7.37.89
17	1.17	899	29.31	2263	31.73	4189	59.71	6859	19.19.19	10373	11.23.41	14413	7.29.71	18473	13.29.49	23069	17.23.59
19	1.19	901	17.53	2279	43.53	4199	13.17.19	6877	13.23.23	10387	13.17.47	14467	17.23.37	18491	11.41.41	23161	19.23.53
23	1.23	913	11.83	2291	29.79	4277	7.13.47	6887	71.97	10439	11.13.73	14539	7.31.67	18601	11.19.89	23171	17.29.47
29	1.29	923	13.71	2299	11.11.19	4301	11.17.23	6889	83.83	10469	19.19.29	14573	13.19.59	18791	19.23.43	23177	11.43.49
31	1.31	931	7. 7.19	2303	7. 7.47	4307	59.73	6919	11.17.37	10507	7.19.79	14651	13.23.49	18821	11.29.59	23273	17.37.37
37	1.37	943	23.41	2387	7.11.31	4331	61.71	6923	7.23.43	10571	11.31.31	14663	11.31.43	18907	7.37.73	23287	11.29.73
41	1.41	949	13.73	2401	7. 7.49	4361	7. 7.89	6929	13.13.41	10591	7.17.89	14749	7.43.49	18941	13.31.47	23359	7.47.71
43	1.43	961	31.31	2407	29.83	4399	53.83	7007	11.13.49	10619	7.37.41	14773	11.17.79	19019	13.19.77	23569	13.37.49
47	1.47	979	11.89	2419	41.59	4403	7.17.37	7021	7.17.59	10621	13.19.43	14801	19.19.41	19057	17.19.59	23579	17.19.73
49	7. 7	989	23.43	2431	11.13.17	4433	11.13.31	7031	79.89	10633	7.31.49	14807	13.17.67	19129	11.37.47	23621	13.23.79
53	1.53	1001	7.11.13	2449	31.79	4453	61.73	7049	7.19.53	10693	17.17.37	14819	7.29.73	19133	19.19.53	23693	19.29.43
59	1.59	1003	17.59	2479	37.67	4459	7.13.49	7081	73.97	10759	7.29.53	14839	11.19.71	19159	17.23.49	23777	13.31.59
61	1.61	1007	19.53	2491	47.53	4477	11.11.37	7139	11.11.59	10769	11.11.89	14911	13.31.37	19229	7.41.67	23779	7.43.79
67	1.67	1027	13.79	2501	41.61	4489	67.67	7163	13.19.29	10787	7.23.67	14927	11.23.59	19313	7.31.89	23821	7.41.83
71	1.71	1037	17.61	2527	7.19.19	4543	7.11.59	7189	7.13.79	10829	13.17.49	14993	11.29.47	19343	23.29.29	23851	17.23.61
73	1.73	1067	11.97	2537	43.59	4559	47.97	7259	7.17.61	10879	11.23.43	15041	13.13.89	19363	17.17.67	23903	11.41.53
77	7.11	1073	29.37	2573	31.83	4661	59.79	7267	13.13.13	10933	13.29.29	15059	11.37.37	19393	11.41.43	23959	13.19.97
79	1.79	1079	13.83	2581	29.89	4669	7.23.23	7337	11.23.29	11011	11.13.77	15067	13.19.61	19411	7.47.59	23987	17.17.83
83	1.83	1081	23.47	2597	7. 7.53	4693	13.19.19	7381	11.11.61	11033	11.17.59	15181	17.19.47	19459	11.29.61	24013	11.37.59
89	1.89	1121	19.59	2623	43.61	4697	7.11.61	7387	83.89	11039	7.19.83	15211	7.41.53	19481	11.23.77	24017	7.47.73
91	7.13	1127	7. 7.23	2627	37.71	4717	53.89	7429	17.19.23	11063	13.23.37	15257	11.19.73	19499	17.31.37	24037	13.43.43
97	1.97	1139	17.67	2639	7.13.29	4753	7. 7.97	7469	7.11.97	11077	11.19.53	15281	7.37.59	19513	13.19.79	24149	19.31.41
119	7.17	1147	31.37	2701	37.73	4757	67.71	7511	7.29.37	11137	7.37.43	15283	17.29.31	19573	23.23.37	24157	17.29.49
121	11.11	1157	13.89	2717	11.13.19	4807	11.19.23	7553	7.13.83	11191	19.19.31	15317	17.17.53	19663	7.53.53	24187	19.19.67
133	7.19	1159	19.61	2737	7.17.23	4819	61.79	7567	7.23.47	11297	11.13.79	15341	23.23.29	19669	13.17.89	24211	11.31.71
143	11.13	1183	7.13.13	2747	41.67	4823	7.13.53	7579	11.13.53	11323	13.13.67	15379	13.13.91	19691	7.29.97	24299	11.47.47
161	7.23	1189	29.41	2759	31.89	4879	7.17.41	7657	13.19.31	11339	17.23.29	15407	7.31.71	19703	17.19.61	24353	7.49.71
169	13.13	1207	17.71	2773	47.59	4891	67.73	7663	79.97	11407	11.17.61	15433	11.23.61	19721	13.37.41	24367	7.59.59
187	11.17	1219	23.53	2783	11.11.23	4897	59.83	7667	11.17.41	11431	7.23.71	15457	13.29.41	19747	13.31.49	24389	29.29.29
203	7.29	1241	17.73	2809	53.53	4901	13.13.29	7733	11.19.37	11501	7.31.53	15463	7.47.47	19943	11.37.49	24541	11.23.97
209	11.19	1247	29.43	2813	29.97	4913	17.17.17	7843	11.23.31	11543	7.17.97	15521	11.17.83	19981	13.29.53	24563	11.29.77
217	7.31	1261	13.97	2821	7.13.31	4921	7.19.31	7847	7.19.59	11609	13.19.47	15523	19.19.43	19987	11.23.79	24583	13.31.61
221	13.17	1271	31.41	2849	7.11.37	4961	11.11.41	7889	7.23.49	11687	13.29.31	15617	7.23.97	20033	13.23.67	24679	23.29.37
247	13.19	1273	19.67	2867	47.61	4991	7.23.31	7921	89.89	11713	13.17.53	15631	11.29.49	20069	7.47.61	24769	17.31.47
253	11.23	1309	7.11.17	2873	13.13.17	5041	53.97	7943	13.13.47	11737	11.11.97	15691	13.17.71	20111	13.17.91	24817	13.23.83
259	7.37	1331	11.11.11	2881	43.67	5083	13.17.23	7973	7.17.67	11753	7.23.73	15799	7.37.61	20119	11.31.59	24827	11.37.61
287	7.41	1333	31.43	2891	7. 7.59	5117	7.17.43	8029	7.31.37	11767	7.41.41	15827	17.19.49	20167	7.43.67	24857	7.53.67
289	17.17	1343	17.79	2911	41.71	5141	53.97	8041	11.17.43	11803	11.29.37	15841	7.31.73	20213	17.29.41	24863	23.23.47
299	13.23	1349	19.71	2923	37.79	5159	7.11.67	8051	83.97	11837	7.19.89	15847	13.23.53	20237	7.49.59	24871	17.19.77
301	7.43	1357	23.59	2989	7. 7.61	5183	71. 7. 3	8099	7.13.89	11849	17.17.41	15953	7.43.53	20273	11.19.97	24893	11.31.73
319	11.29	1363	29.47	2993	41.73	5203	11.11.43	8107	11.11.67	11869	11.13.83	15979	19.29.29	20339	11.43.43	24983	7.43.83
323	17.19	1369	37.37	3007	31.97	5239	13.13.31	8113	7.19.61	11891	11.23.47	16027	11.31.47	20377	7.41.71	25039	7.49.73
329	7.47	1387	19.73	3053	43.71	5251	59.89	8177	13.17.37	11951	17.19.37	16031	17.23.41	20387	19.29.37	25051	13.41.47
341	11.31	1403	23.61	3059	7.19.23	5291	11.13.37	8281	13.13.49	11977	7.29.59	16037	7.29.79	20461	7.37.79	25069	11.43.53
343	7. 7. 7	1411	17.83	3071	37.83	5293	67.79	8303	19.19.23	11999	13.13.71	16093	11.19.77	20501	13.19.83	25123	7.37.97
361	19.19	1421	7. 7.29	3127	53.59	5329	73.73	8323	7.29.41	12103	13.19.49	16121	7.47.49	20519	17.17.71	25193	7.59.61
371	7.53	1457	31.47	3139	43.73	5369	7.13.59	8381	17.17.29	12121	17.23.31	16133	13.17.73	20539	19.23.47	25201	11.29.79
377	13.29	1463	7.11.19	3149	47.67	5423	11.17.29	8437	11.13.59	12167	23.23.23	16169	19.23.37	20677	23.29.31	25259	13.29.67
391	17.23	1501	19.79	3157	7.11.41	5429	61.89	8449	7.17.71	12173	7.37.47	16211	13.29.43	20683	13.37.43	25327	19.31.43
403	13.31	1513	17.89	3179	11.17.17	5453	7.19.41	8533	7.23.53	12259	13.23.41	16337	17.31.31	20723	17.23.53	25333	11.47.49
407	11.37	1517	37.41	3211	13.13.19	5467	7.11.71	8569	11.19.41	12331	11.19.59	16393	13.13.97	20801	11.31.61	25493	13.37.53
413	7.59	1519	7. 7.31	3233	53.61	5491	17.17.19	8591	11.11.71	12337	13.13.73	16399	23.23.31	20923	7.49.61	25517	17.19.79
427	7.61	1537	29.53	3239	41.79	5551	7.13.61	8633	89.97	12341	7.41.43	16511	11.19.79	20951	7.41.73	25543	7.41.89
437	19.23	1541	23.67	3283	7. 7.67	5561	67.83	8671	13.23.29	12383	7.29.61	16523	13.31.41	20999	11.23.83	25631	19.19.71
451	11.41	1547	7.13.17	3289	11.13.23	5593	7.17.47	8687	7.17.73	12397	11.23.49	16549	13.19.67	21049	7.31.97	25721	17.17.89
469	7.67	1573	11.11.13	3293	37.89	5609	71.79	8723	11.13.61	12427	17.17.43	16643	11.17.89	21097	17.17.73	25783	19.23.59
473	11.43	1577	19.83	3311	7.11.43	5621	7.11.73	8729	7.29.43	12493	13.31.31	16687	11.37.41	21197	11.41.47	25789	17.37.41
481	13.37	1591	37.43	3337	47.71	5681	13.19.23	8789	11.17.47	12529	11.17.67	16709	11.31.49	21199	17.29.43	25823	17.31.49
493	17.29	1633	23.71	3367	7.13.37	5687	11.11.47	8827	7.13.97	12617	11.31.37	16807	7.49.49	21229	13.23.71	25897	19.29.47
497	7. 71	1643	31.53	3397	43.79	5719	7.19.43	8833	11.11.73	12673	19.23.29	16813	17.23.43	21299	19.19.59	25921	23.23.49
511	7.73	1649	17.97	3403	41.83	5723	59.97	8897	7.31.41	12691	7.37.49	16849	7.29.83	21359	13.31.53	25991	7.47.79
517	11.47	1679	23.73	3431	47.73	5767	73.79	8911	7.19.67	12719	7.23.79	16907	11.29.53	21371	7.43.71	26011	19.37.37
527	17.31	1681	41.41	3451	7.17.29	5797	11.17.31	8957	13.13.53	12727	11.13.89	16933	7.41.59	21373	11.29.67	26047	7.61.61
529	23.23	1691	19.89	3479	7. 7.71	5819	11.23.23	8959	17.17.31	12749	11.19.61	16951	11.23.67	21413	19.23.49	26077	29.29.31
533	13.41	1711	29.59	3481	59.59	5831	7.17.49	8987	11.19.43	12803	7.31.59	16967	19.19.47	21437	13.17.97	26117	13.41.49
539	7. 7.11	1729	7.13.19	3509	11.11.29	5863	11.13.41	8993	17.23.23	12857	13.23.43	17017	13.17.77	21497	7.37.83	26129	17.29.53
551	19.29	1739	37.47	3551	53.67	5887	7.29.29	9061	13.17.41	12901	7.19.97	17051	17.17.59	21571	11.37.53	26197	17.23.67
553	7.79	1763	41.43	3553	11.17.19	5893	71.83	9139	13.19.37	12943	7.43.43	17081	19.29.31	21607	17.31.41	26257	11.31.77
559	13.43	1769	29.61	3569	43.83	5917	61.97	9163	11.17.49	13013	13.13.77	17119	17.19.53	21641	17.19.67	26273	13.43.47
581	7.83	1771	7.11.23	3577	7. 7.73	5929	11.11.49	9251	11.29.29	13039	13.17.59	17143	7.31.79	21689	23.23.41	26299	13.17.91
583	11.53	1813	7. 7.37	3589	37.97	5957	7.23.37	9269	13.23.31	13079	11.29.41	17329	13.31.43	21793	19.31.37	26341	7.53.71
589	19.31	1817	23.79	3599	59.61	5963	67.89	9317	11.11.77	13091	13.19.53	17347	11.11.83	21827	13.23.73	26353	19.19.73
611	13.47	1829	31.59	3619	7.11.47	6059	73.83	9331	7.31.43	13237	7.31.61	17353	7.37.67	21853	13.41.41	26381	23.31.37
623	7.89	1843	19.97	3649	41.89	6061	11.19.29	9361	11.23.37	13243	17.19.41	17437	7.47.53	21889	7.53.59	26411	11.49.49
629	17.37	1849	43.43	3689	7.17.31	6083	7.11.79	9367	17.19.29	13277	11.17.71	17459	13.17.79	21973	7.43.73	26477	11.29.83
637	7. 7.13	1859	11.13.13	3703	7.23.23	6097	7.13.67	9401	7.17.79	13351	13.13.79	17501	11.37.43	21983	13.19.89	26609	11.41.59
649	11.59	1891	31.61	3713	47.79	6137	17.19.19	9409	97.97	13357	19.19.37	17507	7.41.61	22021	19.19.61	26611	13.23.89
667	23.29	1909	23.83	3721	61.61	6149	11.13.43	9443	7.19.71	13363	7.23.83	17537	13.19.71	22043	7.47.67	26657	19.23.61
671	11.61	1927	41.47	3731	7.13.41	6241	79.79	9499	7.23.59	13409	11.23.53	17629	17.17.61	22099	11.41.49	26767	13.29.71
679	7.97	1943	29.67	3751	11.11.31	6251	7.19.47	9503	13.17.43	13481	13.17.61	17641	13.23.59	22103	23.31.31	26789	7.43.89
689	13.53	1961	37.53	3757	13.17.17	6253	13.13.37	9541	7.29.47	13489	7.41.47	17689	19.19.49	22231	11.43.47	26809	17.19.83
697	17.41	2009	7. 7.41	3773	7.11.49	6293	7.29.31	9559	11.11.79	13547	19.23.31	17719	13.29.47	22243	13.29.59	26939	11.31.79
703	19.37	2021	43.47	3827	43.89	6307	7.17.53	9581	11.13.67	13583	17.17.47	17759	7.43.59	22253	17.17.77	26999	19.29.49
713	23.31	2023	7.17.17	3857	7.19.29	6319	71.89	9583	9.37.37	13601	7.29.67	17797	13.37.37	22477	13.19.91	27001	13.31.67
731	17.43	2047	23.89	3869	53.73	6391	7.11.83	9709	7.19.73	13651	11.17.73	17917	19.23.41	22517	11.23.89	27047	17.37.43
737	11.67	2057	11.11.17	3871	7. 7.79	6409	13.17.29	9821	7.23.61	13717	11.29.43	17963	11.23.71	22591	19.29.41	27083	7.53.73
767	13.59	2059	29.71	3887	13.13.23	6413	11.11.53	9823	11.19.47	13727	7.31.53	18011	7.31.83	22607	13.37.47	27097	7.49.79
779	19.41	2077	31.67	3901	47.83	6461	7.13.71	9877	7.17.83	13871	11.13.97	18031	13.19.73	22631	7.53.61	27209	13.23.91
781	11.71	2093	7.13.23	3913	7.13.43	6479	11.19.31	9889	11.29.31	13889	17.19.43	18047	7.29.89	22649	11.29.71	27269	11.47.67
793	13.61	2107	7. 7.43	3953	59.67	6497	73.89	9911	11.17.53	13949	13.29.37	18073	11.31.53	22661	17.31.43	27307	7.47.83
799	17.47	2117	29.73	3971	11.19.19	6499	67.97	9947	7.23.49	13981	11.31.41	18139	11.17.97	22673	7.41.79	27347	23.29.41
803	11.73	2173	41.53	3977	41.97	6517	7.19.49	9971	13.13.59	14003	11.19.67	18179	7.49.53	22747	23.23.43	27391	13.43.49
817	19.43	2183	37.59	4067	7. 7.83	6557	79.83	10013	17.19.31	14027	13.13.83	18239	13.23.61	22831	17.17.79	27401	11.47.53
833	7. 7.17	2197	13.13.13	4081	7.11.53	6601	7.23.41	10043	11.11.83	14053	13.23.47	18241	17.29.37	22847	11.31.67	27511	11.41.61
841	29.29	2201	31.71	4087	61.67	6643	7.13.73	10051	19.23.23	14063	7.41.49	18259	19.31.31	22919	13.41.43	27521	13.29.73
847	7.11.11	2209	47.47	4123	7.19.31	6647	17.17.23	10127	13.19.41	14147	7.43.47	18343	13.17.83	22933	17.19.71	27671	7.59.67
851	23.37	2231	23.97	4147	11.13.29	6721	11.13.47	10153	11.13.71	14161	17.17.49	18361	7.43.61	22981	7.49.67	27683	19.31.47

TABLE I—*continued.*

27761	17.23.71	32923	11.41.73	38617	23.23.73	44573	29.29.53	50933	31.31.53	58261	29.41.49	65941	23.47.61	74617	29.31.83
27797	19.19.77	32981	13.43.59	38657	29.31.43	44591	17.43.61	51119	17.31.97	58327	17.47.73	66091	29.43.53	74777	37.43.47
27839	7.41.97	33019	7.53.89	38663	23.41.41	44603	13.47.73	51127	29.41.43	58349	19.37.83	66101	19.49.71	74783	17.53.83
27869	29.31.31	33031	17.29.67	38743	17.43.53	44659	11.37.71	51271	11.59.79	58351	23.43.59	66139	19.59.59	74849	29.29.89
27907	11.43.59	33041	19.37.47	38857	13.49.61	44689	23.29.67	51301	29.29.61	58357	13.67.67	66263	23.43.67	74971	13.73.79
27931	17.31.53	33077	11.31.97	38893	19.23.89	44737	11.49.83	51313	23.23.97	58609	29.43.47	66317	17.47.83	74989	31.41.59
28033	17.17.97	33263	29.31.37	38909	13.41.73	44863	17.29.91	51319	19.37.73	58619	11.73.73	66439	29.29.79	75107	19.59.67
28037	23.23.53	33271	7.49.97	38927	7.67.83	44891	11.53.77	51359	23.29.77	58621	31.31.61	66521	17.43.91	75313	29.49.53
28249	13.41.53	33299	7.67.71	38947	17.29.79	44957	11.61.67	51389	13.59.67	58867	37.37.43	66649	11.73.83	75383	11.77.89
28303	11.31.83	33337	17.37.53	39061	11.53.67	45103	23.37.53	51667	11.61.77	59059	13.59.77	66787	29.47.49	75509	23.49.67
28379	13.37.59	33449	13.31.83	39091	13.31.97	45167	31.31.47	51701	13.41.97	59143	17.49.71	66833	13.53.97	75563	19.41.97
28391	11.29.89	33497	19.41.43	39121	19.29.71	45227	13.49.71	51709	7.83.89	59177	17.59.59	66913	11.77.79	75701	17.61.73
28469	7.49.83	33511	23.31.47	39151	17.47.49	45253	13.59.59	51887	11.53.89	59179	23.31.83	66953	23.41.71	75739	23.37.89
28519	19.19.79	33553	13.29.89	39259	11.43.83	45353	19.31.77	51901	17.43.71	59267	13.47.97	67067	13.67.77	75757	11.71.97
28543	17.23.73	33583	11.43.71	39263	7.71.79	45479	7.73.89	51911	23.37.61	59363	23.29.89	67081	37.37.49	75779	11.83.83
28567	11.49.53	33611	19.29.61	39347	11.49.73	45493	7.67.97	52049	23.31.73	59413	19.53.59	67201	17.59.67	75803	17.49.91
28577	17.41.41	33649	19.23.77	39353	23.29.59	45619	19.49.49	52111	31.41.41	59641	19.43.73	67229	23.37.79	75809	41.43.43
28609	7.61.67	33733	7.61.79	39401	31.31.41	45733	19.29.83	52193	19.41.67	59711	29.29.71	67363	31.41.53	75919	31.31.79
28613	13.31.71	33761	13.49.53	39463	19.31.67	45881	11.43.97	52207	17.37.83	59719	11.61.89	67379	13.71.73	76067	29.43.61
28681	23.29.43	33781	11.37.83	39479	11.37.97	45899	7.79.83	52283	11.49.97	59731	23.49.53	67469	19.53.67	76153	23.43.77
28717	13.47.47	34099	13.43.61	39527	29.29.47	45917	7.73.89	52327	11.67.71	59737	31.41.47	67609	17.41.97	76183	29.37.71
28747	17.19.89	34151	13.37.71	39589	11.59.61	45961	19.41.59	52417	23.43.53	59831	19.47.67	67673	31.37.59	76313	17.67.67
28823	19.37.41	34153	17.41.49	39689	13.43.71	46013	11.47.89	52421	19.31.89	59983	19.41.77	67811	19.43.83	76531	29.29.91
28853	11.43.61	34237	7.67.73	39701	29.37.37	46057	11.53.79	52577	29.49.37	60137	11.71.77	67963	19.49.73	76609	13.71.83
28861	19.31.49	34279	7.59.83	39767	19.23.91	46079	11.59.71	52687	19.47.59	60233	29.31.67	68191	19.37.97	76751	23.47.71
28897	11.37.71	34307	13.29.91	39809	11.47.77	46139	29.37.43	52693	23.29.79	60329	23.43.61	68231	31.31.71	76849	31.37.67
29003	13.23.97	34357	17.43.47	39923	13.37.83	46163	13.53.67	52871	13.49.83	60367	17.53.67	68263	13.59.89	76921	13.61.97
29029	13.29.77	34397	11.53.59	33997	23.37.47	46207	23.41.49	52969	23.47.49	60421	23.37.71	68381	19.59.61	77077	13.77.77
29087	17.29.59	34447	19.37.49	40033	19.43.49	46397	13.43.83	53009	11.61.79	60431	7.89.97	68413	37.43.43	77221	31.47.53
29197	7.43.97	34481	29.29.41	40061	7.59.97	46483	23.43.47	53041	29.31.59	60593	13.59.79	68479	31.47.47	77231	17.59.77
29203	19.29.53	34523	19.23.79	40139	11.41.89	46501	13.49.73	53053	13.53.77	60673	17.43.83	68651	11.79.79	77273	19.49.83
29233	23.31.41	34529	11.43.73	40223	19.29.73	46531	19.31.79	53131	13.61.67	60697	23.29.91	68747	23.49.61	77341	11.79.89
29279	19.23.67	34639	11.47.67	40369	7.73.79	46657	13.37.97	53159	17.53.59	60791	31.37.53	68761	19.47.77	77441	23.37.91
29281	7.47.89	34727	11.41.77	40549	23.41.43	46699	17.41.67	53363	17.43.73	60809	17.49.73	68809	13.67.79	77503	17.47.97
29309	7.53.79	34751	19.31.59	40579	17.31.77	46787	13.59.61	53371	19.53.53	61013	17.37.97	68839	23.41.73	77519	13.67.89
29323	7.59.71	34799	17.23.89	40651	13.53.59	46903	17.31.89	53447	19.29.97	61061	13.61.77	68921	41.41.41	77531	31.41.61
29341	13.37.61	34891	23.37.41	40687	23.29.61	47027	31.37.41	53533	17.47.67	61103	29.43.49	69139	17.49.83	77539	19.53.77
29393	17.19.91	34937	23.31.49	40733	23.23.77	47047	13.47.77	53599	19.31.91	61171	11.67.83	69161	23.31.97	77653	19.61.67
29419	13.31.73	35003	17.29.71	40807	13.43.73	47081	23.23.89	53621	29.43.43	61183	17.59.61	69223	29.31.77	77891	11.73.97
29563	17.37.47	35017	19.19.97	40817	17.49.49	47089	31.31.49	53641	7.79.97	61321	13.53.89	69277	13.73.73	77959	37.43.49
29627	13.43.53	35113	13.37.73	40843	11.47.79	47101	19.37.67	53669	17.41.77	61393	29.29.73	69331	19.41.89	78131	23.43.79
29711	11.37.73	35131	19.43.43	40919	17.29.83	47141	17.47.59	53801	11.67.73	61427	19.53.61	69377	17.53.77	78269	23.41.83
29783	13.29.79	35287	7.71.71	40931	11.61.61	47329	19.47.53	53867	11.59.83	61523	17.47.77	69479	17.61.67	78329	29.37.73
29791	31.31.31	35309	17.31.67	40937	13.47.67	47357	23.29.71	53909	31.37.47	61541	19.41.79	69509	11.71.89	78647	31.43.59
29939	13.47.49	35351	23.29.53	41041	13.41.77	47377	11.59.73	54131	19.37.77	61699	11.71.79	69629	29.49.49	78767	13.73.83
29963	19.19.83	35441	7.61.83	41123	17.41.59	47437	13.41.89	54223	13.43.97	61789	13.49.97	69797	13.59.91	78913	23.47.73
29971	17.41.43	35443	23.23.67	41209	29.29.49	47519	19.41.61	54379	13.47.89	61831	11.73.77	69803	29.29.83	79007	41.41.47
30073	17.29.61	35557	31.31.37	41251	7.71.83	47641	11.61.71	54431	13.53.79	61841	13.67.71	69967	31.37.61	79079	13.77.79
30107	17.23.77	35563	11.53.61	41287	19.41.53	47647	29.31.53	54457	13.59.71	62033	17.41.89	70151	29.41.59	79237	17.59.79
30149	7.59.73	35581	17.23.91	41323	31.31.43	47753	17.53.53	54473	19.47.61	62123	23.37.73	70153	31.31.73	79249	19.43.97
30217	11.41.67	35629	11.41.79	41393	11.53.71	47771	23.31.67	54653	31.41.43	62197	37.41.41	70219	23.43.71	79261	13.67.91
30229	19.37.43	35711	13.41.67	41419	7.61.97	47821	17.29.97	54739	19.43.67	62279	31.41.49	70301	11.77.83	79477	19.47.89
30317	7.61.71	35819	17.43.49	41477	19.37.59	47957	17.31.91	54839	29.31.61	62377	19.49.67	70547	19.47.79	79507	43.43.43
30349	11.31.89	35867	13.31.89	41503	11.49.77	47971	11.49.89	54901	23.31.77	62567	19.37.89	70577	13.61.89	79553	19.53.79
30503	11.47.59	35929	19.31.61	41633	17.31.79	48139	23.23.91	54929	19.49.59	62647	13.61.79	70633	23.37.83	79591	19.59.71
30527	7.49.89	35987	7.53.97	41699	23.37.47	48203	19.43.59	54961	17.53.61	62651	31.43.47	70649	31.43.53	79663	29.41.67
30659	23.31.43	35989	17.29.73	41741	7.67.89	48209	7.71.97	55063	17.41.79	62699	13.53.91	70699	19.61.61	79763	31.31.83
30793	7.53.83	36049	13.47.59	41791	23.23.79	48223	7.83.83	55223	23.49.49	62909	19.43.77	70889	19.41.91	79849	17.61.77
30821	17.37.49	36113	11.49.67	41819	19.31.71	48269	13.47.79	55309	19.41.71	62953	11.59.97	70907	17.43.97	80011	29.31.89
30889	17.23.79	36163	29.29.43	41971	19.47.47	48373	13.61.61	55361	23.29.83	63017	29.41.53	71021	29.31.79	80017	23.49.71
30899	11.53.53	36223	11.37.89	42029	13.53.61	48389	11.53.83	55447	7.89.89	63121	17.47.79	71071	13.71.77	80063	23.59.59
30943	11.29.97	36271	19.23.83	42067	23.3 .59	48433	17.37.77	55451	11.71.71	63181	23.41.67	71111	17.47.89	80189	17.53.89
31027	19.23.71	36281	7.71.73	42097	11.43.89	48461	23.43.49	55537	19.37.79	63257	17.61.61	71179	17.53.79	80401	37.41.53
31031	13.31.77	36421	11.43.77	42107	13.41.79	48503	13.41.91	55601	13.47.91	63307	29.37.59	71213	17.59.71	80417	29.47.59
31093	17.31.59	36517	13.53.53	42143	17.37.67	48691	23.29.73	55637	23.41.59	63403	19.47.71	71299	37.41.47	80507	31.49.53
31117	29.29.37	36569	13.29.97	42253	29.31.47	48739	17.47.61	55693	11.61.83	63427	17.41.91	71393	31.47.49	80771	37.37.59
31171	7.61.73	36593	23.37.43	42347	17.47.53	48749	29.41.41	55811	17.49.67	63437	11.73.79	71467	11.73.89	80801	17.49.97
31211	23.23.59	36613	19.41.47	42389	19.23.97	48887	19.31.83	55883	29.41.47	63457	23.31.89	71489	11.67.97	80869	17.67.71
31213	13.49.49	36673	13.31.91	42413	7.73.83	48919	13.53.71	55981	17.37.89	63583	13.67.73	71497	19.53.71	81133	13.79.79
31217	19.31.53	36707	11.47.71	42427	19.29.77	48977	17.43.67	55991	13.59.73	63661	13.59.83	71687	19.49.77	81257	11.83.89
31291	13.29.83	36757	7.59.89	42439	31.37.37	48983	11.61.73	56129	37.37.41	63779	23.47.59	71891	29.37.67	81263	19.47.91
31331	17.19.97	36859	29.31.41	42517	17.41.61	49039	19.29.89	56203	31.37.49	63829	29.31.71	71921	23.53.59	81313	31.43.61
31339	11.37.77	36917	19.29.67	42527	23.43.43	49049	13.49.77	56287	17.43.77	63971	17.53.71	72127	11.79.83	81437	31.37.71
31349	23.29.47	36941	17.41.53	42559	11.53.73	49147	17.49.59	56303	13.61.71	63973	19.37.91	72163	13.61.91	81461	29.53.53
31423	7.67.67	37037	13.37.77	42581	11.49.79	49217	7.79.89	56327	23.31.79	64061	29.47.47	72197	23.43.73	81577	29.29.97
31433	17.43.43	37051	7.67.79	42679	13.49.67	49321	31.37.43	56347	29.29.67	64141	17.49.77	72239	29.47.53	81673	23.53.67
31447	13.41.59	37111	17.37.59	42809	13.37.89	49343	19.49.53	56357	7.83.97	64343	37.37.47	72283	41.41.43	81809	29.31.91
31487	23.37.37	37259	19.37.53	42883	19.37.61	49379	11.67.67	56551	11.53.97	64387	31.31.67	72293	13.67.83	81033	19.59.73
31537	11.47.61	37271	13.47.61	42911	11.47.83	49487	17.41.71	56693	13.49.89	64543	19.43.79	72427	23.47.67	81923	17.61.79
31691	11.43.67	37303	7.73.73	42997	19.31.73	49567	7.73.97	56699	31.31.59	64607	23.53.53	72529	29.41.61	81991	17.53.91
31801	11.49.59	37367	11.43.79	43043	13.43.77	49619	29.29.59	56729	17.47.71	64657	19.41.83	72557	37.37.53	82087	23.43.83
31837	13.31.79	37417	17.31.71	43129	17.43.59	49691	17.37.79	56749	11.67.77	64699	23.29.97	72611	23.41.77	82147	13.71.89
31901	19.23.73	37433	11.41.83	43301	19.43.53	49751	13.43.89	56791	19.41.61	64757	29.29.77	72709	17.47.91	82159	11.77.97
31913	7.47.97	37453	13.43.67	43381	13.47.71	49837	19.43.61	56867	19.41.73	64823	11.71.83	72713	19.43.89	82271	23.49.73
31939	19.41.41	37553	17.47.47	43483	11.59.67	49913	19.37.71	56869	29.37.53	64883	23.31.91	72917	13.71.79	82289	19.61.71
32021	11.41.71	37559	23.23.71	43493	23.31.61	49973	11.59.77	57013	11.71.73	65059	17.43.89	73073	13.73.77	82369	41.41.49
32129	19.19.89	37583	13.49.59	43529	19.29.79	49979	23.41.53	57017	23.37.67	65087	11.61.97	73219	17.59.73	82547	23.37.97
32147	17.31.61	37741	11.47.73	43687	7.79.79	50141	19.29.91	57133	19.31.97	65189	19.47.73	73511	19.53.73	82621	29.37.77
32153	11.37.79	37789	23.31.53	43741	17.31.83	50149	11.47.97	57187	13.53.83	65219	11.77.77	73549	19.49.79	82777	23.59.61
32227	13.37.67	37843	13.41.71	43747	11.4 .97	50209	23.37.59	57239	17.37.91	65231	37.41.43	73573	29.43.59	82859	19.49.89
32269	23.23.61	37927	17.23.97	43771	13.37.91	50297	13.53.73	57293	23.47.53	65317	31.43.49	73627	17.61.71	82861	41.43.47
32383	13.47.53	37961	17.29.77	43877	17.29.89	50323	13.49.79	57319	31.43.43	65453	29.37.61	73997	31.31.77	83083	13.77.83
32453	17.23.83	37999	13.37.79	43907	23.23.83	50431	29.37.47	57523	23.41.61	65527	23.37.77	74119	19.47.83	83143	29.47.61
32509	19.29.59	38003	7.61.89	43993	29.37.41	50623	23.31.71	57749	17.43.49	65533	13.71.71	74137	17.49.89	83147	17.67.73
32513	13.41.61	38171	19.41.49	44051	29.31.49	50653	37.37.37	57761	11.59.89	65593	11.67.89	74333	37.41.49	83237	23.47.77
32627	7.59.79	38269	11.49.71	44149	17.49.53	50713	13.47.83	57851	17.41.83	65627	29.31.73	74347	19.43.91	83249	17.59.83
32683	23.29.49	38291	11.59.59	44161	13.43.79	50807	23.47.47	57889	13.61.73	65773	17.53.73	74359	23.53.61	83509	37.37.61
32759	17.41.47	38369	17.37.61	44233	7.71.89	50813	17.49.61	57967	13.49.91	65807	17.49.79	74399	13.59.97	83549	29.43.67
32851	19.19.91	38399	19.43.47	44239	13.41.83	50869	13.43.91	58007	19.43.17	65819	13.61.83	74431	31.49.49	83581	19.53.83
32879	11.49.61	38471	17.31.73	44321	23.41.47	50881	17.41.73	58223	11.67.79	65863	7.97.97	74497	23.41.79	83731	13.37.73

TABLE I—*continued.*

83819	29.49.59	94537	17.67.83	106361	31.47.73	119351	41.41.71	134461	43.53.59	150479	37.49.83	169979	43.59.67	191479	43.61.73
83927	23.41.89	94643	31.43.71	106477	41.42.53	119527	17.79.89	134539	19.73.97	150499	19.89.89	170093	47.47.77	191737	43.49.91
83993	13.71.91	94963	11.89.97	106571	19.71.79	119621	37.53.61	134603	41.49.67	150811	23.79.83	170471	49.49.71	191771	37.71.73
84293	11.79.97	94987	43.47.47	106597	37.43.67	119843	37.41.79	134657	17.89.89	150997	37.53.77	170569	49.59.59	191807	47.53.77
84323	37.43.53	95201	31.37.83	106799	19.73.77	119939	31.53.73	134749	47.47.61	151219	37.61.67	170897	29.71.83	192089	47.61.67
84419	29.41.71	95207	29.49.67	106967	37.49.59	120001	31.49.79	134977	43.43.73	151621	31.67.73	171011	41.43.97	192577	41.61.77
84461	13.73.89	95353	17.71.79	107113	43.47.53	120061	19.71.89	135013	37.41.89	151807	31.59.83	171349	53.53.61	192647	29.73.91
84487	13.67.97	95497	29.37.89	107203	23.59.79	120377	17.73.97	135169	29.59.79	151951	47.53.61	171503	41.47.89	193027	43.67.67
84607	19.61.73	95557	17.73.77	107423	17.71.89	120773	23.59.89	135191	31.49.89	152233	41.47.79	171593	29.61.97	193397	41.53.89
84721	19.49.91	95779	19.71.71	107543	41.43.61	120787	43.53.53	135407	43.47.67	152279	29.59.89	171667	41.53.79	193471	31.79.79
84767	29.37.79	95933	23.43.97	107653	13.91.91	120931	31.47.83	135539	23.71.83	152561	41.61.61	171749	41.59.71	193697	49.59.67
85157	31.41.67	96019	29.43.77	107677	29.47.79	120959	29.43.97	135751	41.43.77	152693	43.53.67	171787	23.77.97	194287	37.59.89
85211	37.47.49	96031	13.83.89	107707	37.41.71	121303	31.43.91	135877	47.49.59	152789	23.73.91	171941	29.77.77	194873	41.49.97
85241	13.79.83	96089	37.49.53	107849	31.49.71	121307	29.47.89	136091	23.61.97	152969	19.83.97	172081	31.61.91	195037	41.67.71
85291	19.67.67	96197	19.61.83	107909	29.61.61	121423	29.53.79	136213	29.61.77	152971	41.41.91	172391	31.67.83	195349	43.59.77
85399	23.47.79	96209	23.47.89	107911	31.59.59	121429	19.77.83	136367	23.77.77	153223	49.53.59	172457	37.59.79	195841	37.67.79
85529	31.31.89	96301	23.53.79	108031	23.61.77	121471	37.49.67	136369	31.53.83	153467	43.43.83	172927	29.67.89	195889	31.71.89
85583	23.61.61	96347	23.59.71	108151	37.37.79	121481	29.59.71	136591	19.79.91	153497	29.67.79	173719	23.83.91	196037	43.47.97
85697	17.71.71	96773	29.47.71	108199	29.41.91	121739	23.67.79	136793	29.53.89	153811	43.49.73	173789	37.61.77	196601	47.47.89
85813	23.41.91	96937	31.53.59	108241	47.47.49	121841	37.37.89	136817	41.47.71	153881	19.89.91	173879	31.71.79	196789	47.53.79
86071	17.61.83	97051	37.43.61	108491	23.53.89	122059	47.49.53	136867	17.83.97	154283	41.53.71	173999	49.53.67	196883	47.59.71
86317	19.59.77	97097	13.77.97	108647	17.77.83	122213	17.79.91	137149	23.67.89	154301	47.49.67	174251	31.73.77	197173	37.73.73
86359	13.73.91	97199	37.37.71	108737	19.59.97	122317	13.97.97	137381	37.47.79	154327	37.43.97	174511	47.47.79	197213	53.61.61
86387	41.43.49	97291	17.59.97	109091	43.43.59	122507	37.43.77	137641	49.53.53	154541	29.73.73	174529	37.53.89	197579	41.61.79
86549	23.53.71	97309	31.43.73	109127	29.53.71	122543	31.59.67	137677	37.61.61	154693	41.49.77	174881	43.49.83	197743	41.53.91
86621	19.47.97	97619	31.47.67	109319	23.49.97	122549	41.49.61	137683	17.89.91	154757	43.59.61	174887	47.61.61	198121	31.77.83
86681	29.49.61	97643	29.37.91	109411	23.67.71	122567	23.73.73	137837	29.49.97	154771	37.47.89	175273	49.49.73	198559	23.89.97
86779	23.49.77	97679	19.53.97	109417	29.49.77	122713	41.41.73	137953	29.67.71	154919	37.53.79	175357	41.47.91	198653	37.59.91
86797	29.41.73	97867	31.41.77	109573	19.73.79	122759	19.71.91	138043	31.61.73	154993	37.59.71	175483	43.53.77	198737	29.77.89
86903	43.43.47	97997	43.43.53	109837	17.71.91	123281	43.47.61	138047	37.41.91	155617	43.47.77	175711	29.73.83	199283	49.49.83
87079	31.53.53	98021	19.67.77	110081	31.53.67	123287	31.41.97	138229	31.49.91	155701	29.59.91	175741	43.61.67	199439	53.53.71
87131	11.89.89	98039	17.73.79	110449	17.73.89	123443	19.73.89	139019	43.53.61	156271	31.71.71	175861	37.49.97	199723	29.71.97
87203	29.31.97	98189	13.83.91	110483	17.67.97	123469	37.47.71	139159	31.67.67	156839	47.47.71	176009	37.67.71	199781	29.83.83
87397	17.53.97	98371	23.47.91	110593	37.49.61	123481	19.67.97	139231	37.53.71	156907	41.43.89	176249	23.79.97	199969	49.53.77
87451	31.31.91	98441	41.49.49	110639	31.43.83	123487	23.59.91	139277	41.43.79	156953	31.61.83	176351	49.59.61	200263	49.61.67
87703	17.67.77	98477	19.71.73	110741	37.41.73	123883	43.43.67	139357	23.73.83	157339	19.91.91	176407	29.77.79	200291	31.71.91
88021	23.43.89	98513	29.43.79	110837	23.61.79	124033	29.47.91	139523	41.41.83	157441	29.61.89	176587	41.59.73	200423	43.59.79
88111	17.71.73	98687	29.41.83	110887	31.49.73	124313	43.49.59	139601	37.49.77	157619	23.77.89	176813	29.67.91	200531	41.67.73
88319	31.37.77	99029	43.47.49	110929	23.53.91	124579	37.37.91	139751	29.61.79	158249	37.47.91	176861	47.53.71	200777	41.59.83
88537	29.43.71	99061	23.59.73	110983	29.43.89	124583	19.79.83	139867	29.53.91	158401	23.71.97	177331	47.49.77	200873	37.61.89
88559	19.59.79	99179	41.41.59	111259	31.37.97	124867	23.61.89	139909	23.77.79	158417	49.53.61	177413	31.59.97	201019	47.47.91
88561	11.83.97	99499	29.47.73	111469	17.79.83	124903	29.59.73	140231	23.67.91	158447	23.83.83	177571	41.61.71	201407	31.73.89
88837	37.49.49	99613	23.61.71	111569	31.59.61	125173	41.43.71	140353	19.83.89	158543	29.71.77	178303	37.61.79	201469	31.67.97
88877	31.47.61	99619	13.79.97	111671	43.49.53	125579	17.83.89	140483	47.49.61	158629	41.53.73	178451	37.53.91	201971	43.61.77
88881	39.43.53	99769	19.59.89	111967	19.71.83	125599	29.61.71	140671	41.47.73	158711	41.49.79	178771	19.97.97	202279	37.71.77
88987	23.53.73	99937	37.37.73	112189	31.47.77	125689	37.43.79	140777	17.91.91	159359	37.59.73	178777	31.73.79	202429	47.59.73
89033	23.49.79	100181	17.71.83	112201	29.53.73	125741	23.71.77	140833	31.59.77	159371	31.53.97	178801	41.49.89	202831	43.53.89
89059	29.37.83	100223	31.53.61	112229	13.89.97	125911	37.41.83	141169	43.49.67	159659	43.47.79	179353	43.43.97	203021	23.91.97
89089	13.77.89	100303	23.49.89	112259	29.49.79	126077	31.49.83	141329	31.47.97	159929	31.67.77	179869	43.47.89	203203	29.77.91
89093	41.41.53	100409	31.41.79	112423	19.61.97	126217	19.73.91	141599	37.43.89	159953	17.97.97	180041	43.53.79	203267	31.79.83
89243	19.61.77	100567	19.67.79	112493	23.67.73	126469	29.49.89	141659	49.49.59	160003	43.61.61	180127	43.59.71	203557	47.61.71
89267	17.59.89	100589	17.61.97	112627	41.41.67	126511	31.53.77	141839	29.67.73	160247	37.61.71	180359	41.53.83	203899	29.79.89
89311	31.43.67	100793	17.77.77	112631	23.59.83	126697	31.61.67	141911	19.77.97	160433	41.43.91	180967	37.67.73	204379	43.49.97
89503	37.41.59	100891	29.49.71	112651	19.77.77	126947	37.47.73	142013	29.59.83	160673	31.71.73	180989	29.79.79	204551	43.67.71
89531	13.71.97	100949	29.59.59	112789	43.43.61	126973	17.77.97	142373	43.43.77	160867	49.49.67	181189	37.59.83	204967	47.49.89
89557	13.83.83	101177	23.53.83	112847	47.49.49	127253	49.49.53	142639	41.49.71	160979	29.61.91	181843	47.53.73	205057	53.53.73
89621	31.49.59	101251	19.73.73	112931	17.73.91	127571	29.53.83	142721	41.59.59	161161	23.77.91	181937	47.49.79	205163	49.53.79
89623	19.53.89	101371	17.67.89	112961	37.43.71	127673	23.61.91	143153	37.53.73	161257	47.47.73	182183	23.89.89	205261	49.59.71
89723	23.47.83	101639	37.41.67	113119	31.41.89	127903	23.67.83	143227	37.49.79	161269	29.67.83	182329	49.61.61	205349	29.73.97
89981	17.67.79	101773	31.49.67	113129	29.47.83	128207	41.53.59	143491	43.47.71	161357	37.49.89	182573	41.61.73	205379	59.59.59
89999	23.43.91	102011	19.59.91	113297	19.67.89	128401	17.83.91	143507	19.83.91	161713	23.79.89	182683	31.71.83		
90241	31.41.71	102083	31.37.89	113477	29.43.91	128527	43.49.61	143543	23.79.79	161809	43.53.71	182819	41.49.91		
90307	19.49.97	102131	41.47.53	113627	37.37.83	128699	41.43.73	144337	37.47.83	162073	41.59.67	183251	29.71.89		
90383	19.67.71	102419	23.61.73	113693	41.47.59	128723	37.49.71	144491	31.59.79	162239	43.49.77	183347	47.47.83		
90569	41.47.47	102541	41.41.61	114637	29.59.67	128797	37.59.59	144781	37.43.91	162661	29.71.79	183427	31.61.97		
90593	17.73.73	102557	23.49.91	114751	13.91.97	129007	23.71.79	145337	23.71.89	162763	37.53.83	183799	31.77.77		
90601	43.43.49	102601	37.47.59	115103	31.47.79	129109	41.47.67	145591	41.53.67	162781	31.59.89	183911	43.47.91		
90613	31.37.79	102641	31.43.77	115121	19.73.83	129137	29.61.73	145597	19.79.97	162863	23.73.97	184049	41.67.67		
90683	29.53.59	102973	13.89.89	115169	41.53.53	129283	23.73.77	145607	31.61.77	163009	29.73.77	184387	49.53.71		
90919	23.59.67	102979	29.53.67	115333	29.41.97	129301	31.43.97	146071	43.43.79	163057	41.41.97	184493	53.59.59		
91031	29.43.73	103003	17.73.83	115351	13.61.61	129311	29.49.91	146189	29.71.71	163513	47.49.71	184853	31.67.89		
91091	13.77.91	103151	19.61.89	115577	19.77.79	129437	41.41.77	146227	31.53.89	163607	47.59.59	184877	49.49.77		
91273	17.59.91	103243	43.49.49	115661	31.41.91	129673	31.47.89	146261	37.59.67	164027	19.89.97	185173	23.83.97		
91321	29.47.67	103247	23.67.67	115699	37.53.59	129797	31.53.79	146329	41.43.83	164083	31.67.79	185201	43.59.73		
91403	13.79.89	103411	17.77.79	115843	19.67.91	129859	31.59.71	146461	49.49.61	164561	43.43.89	185339	29.77.83		
91471	23.41.97	103447	31.47.71	115943	23.71.71	130181	29.67.67	146657	41.49.73	164761	37.61.73	185791	47.59.67		
91553	29.41.77	103499	11.97.97	116143	37.43.73	130207	19.77.89	146761	17.89.97	164983	37.49.91	186233	43.61.71		
91561	19.61.79	103501	29.43.83	116449	23.61.83	130271	17.79.97	146827	29.61.83	165199	31.73.73	186263	41.59.77		
91637	19.53.91	103649	17.67.91	116501	17.77.89	130331	47.47.59	146969	47.53.59	165347	23.79.91	186277	23.89.91		
91723	37.37.67	103733	29.49.73	116513	37.47.67	130853	19.71.97	146993	23.77.83	165731	53.53.59	186517	37.71.71		
92053	13.73.97	103823	47.47.47	116653	31.53.71	130891	19.83.83	147149	37.41.97	165967	29.59.97	186919	41.47.97		
92167	37.47.53	103873	19.71.77	116809	37.41.77	131279	43.43.71	147343	31.49.97	166093	37.67.67	187331	37.61.83		
92293	17.61.89	103933	37.53.53	116963	31.49.77	131387	37.53.67	147467	31.67.71	166367	43.53.73	187369	29.71.91		
92537	37.41.61	104017	41.43.59	117077	47.47.53	131629	23.59.97	147533	43.47.73	166439	31.53.91	187523	43.49.89		
92659	31.49.61	104081	29.37.97	117079	17.71.97	131747	29.59.77	147559	41.59.61	166453	43.49.79	187829	31.73.83		
92783	31.41.73	104371	29.59.61	117113	17.83.83	132023	47.53.53	148003	47.47.67	166747	41.49.83	188203	53.53.67		
92929	19.67.73	104377	31.37.91	117547	41.47.61	132053	37.43.83	148379	41.47.77	166897	47.53.67	188413	29.73.89		
92939	17.71.77	104489	23.59.77	117649	49.49.49	132211	29.47.97	148603	23.71.91	167243	29.73.79	188471	29.67.97		
93043	19.59.83	104663	13.83.97	117943	29.49.83	132349	37.49.73	148877	53.53.53	167321	41.53.77	188573	31.77.79		
93217	31.31.97	104857	23.47.97	118121	41.43.67	132553	41.53.61	149089	29.53.97	167567	41.61.67	189007	31.67.91		
93439	41.43.53	104951	29.47.77	118243	23.53.97	132587	31.47.91	149389	31.61.79	167713	19.91.97	189157	43.53.83		
93457	13.79.91	105287	13.89.91	118349	29.53.77	132641	23.73.79	149431	23.73.89	167743	43.47.83	189581	49.53.73		
93541	22.49.83	105307	31.43.79	118523	29.61.67	132793	37.37.97	149477	23.67.97	168091	37.59.77	189679	49.49.79		
93757	29.53.61	105413	37.37.77	118531	41.49.59	132799	41.41.79	149513	31.53.91	168119	47.49.73	190153	29.79.83		
93863	23.53.77	105469	19.61.91	118579	19.79.79	133133	19.77.91	149597	43.49.71	168259	43.43.91	190217	37.53.97		
93869	37.43.59	105493	31.41.83	118637	31.43.89	133163	37.59.61	149609	41.41.89	168299	31.61.89	190463	23.91.91		
93931	29.41.79	105659	19.67.83	118657	23.67.77	133517	31.59.73	149611	29.67.77	168683	37.47.97	190747	53.59.61		
94001	23.61.67	105821	29.41.89	119119	17.77.91	133589	19.79.89	149683	43.59.59	169153	47.59.61	190883	37.67.77		
94367	17.61.91	106079	37.47.61	119209	23.71.73	133903	37.47.77	150059	17.91.97	169477	31.71.77	191101	41.59.79		
94423	41.47.49	106097	17.79.79	119239	43.47.59	134261	31.61.71	150307	29.71.73	169901	23.83.89	191149	47.49.53		

The number in question may be, e.g., ..	253561
For a reason which immediately will be obvious, we subtract 200200	2002
	53361
We now subtract 50050	5005
	3311
and finally subtract 3003	3003
	308

$308 = 4 \times 7 \times 11$. Because 308 is divisible by 7 and by 11, the number 253561 must likewise be divisible by 7 and 11, and by using Table I, it will readily be found that $253561 = 37 \times 77 \times 89$.

If, in another case, the low number finally resulting is not divisible by 7, 11, or 13, neither is the investigated number.

(*b*) *Continued Fractions*

As 15/60 can be reduced to 1/4, any fraction can be reduced to a fraction with 1 as numerator. By dividing numerator and denominator of 9/31 by 9, that fraction is transformed into $\frac{1}{31/9}$ which can also be expressed by $\frac{1}{3 + 4/9}$. If 4/9 is treated in the same way $\left(\frac{4}{9} = \frac{1}{2 + 1/4}\right)$, the fraction 9/31 can be written in the form $\cfrac{1}{3 + \cfrac{1}{2 + 1/4}}$. This expression is called a continued fraction.

If the last fraction 1/4 is neglected, the fraction $\frac{1}{3+1/2} = \frac{2}{6+1} = \frac{2}{7}$ is obtained; ignoring the next fraction 1/2 brings us to the fraction 1/3. Both 2/7 and 1/3 are fractions near to 9/31, and consist of numbers smaller than 9 and 31 respectively.

The method demonstrated above is somewhat cumbersome and the same result can be obtained in the following manner. We place the denominator (31) and numerator (9) on either side of a line, and divide the larger number by the smaller. The quotient (3) is placed in a further column, and the remainder (4) in the column of the smaller number, as in the following scheme.

31	9	3
	4	

We enter the last divisor (9) below the last dividend (31), and, as above, divide 9 by 4; the new quotient (2) and the new remainder (1) are placed in their respective columns.

The process is continued until there is a division without remainder; the scheme then reaches the form:

31	9	3
9	4	2
4	1	4
	0	

The quotients are now written in one line, and before them, but in a line below, the ciphers 1 and 0, and below these 0 and 1, as follows:

		3	2	4
1	0			
0	1			

We now multiply the first quotient (3) by the number which stands to the left of, and below it (0), and add the number which stands on the left of the latter (1); the result $(3 \times 0) + 1 = 1$ is written below the figure 3. We carry out the same procedure with the second quotient 2 below which $(2 \times 1) + 0 = 2$ is written. The same is done with the following quotient 4, below which $(4 \times 2) + 1 = 9$ is placed.

		3	2	4
1	0	1	2	9
0	1			

The calculations are then carried out in a similar manner for the quotients in the first line, and the numbers in the third line, giving $(3 \times 1) + 0 = 3$; $(2 \times 3) + 1 = 7$; $(4 \times 7) + 3 = 31$, with which the third line is completed, and we obtain the scheme:

		3	2	4
1	0	1	2	9
0	1	3	7	31

The numbers below the last quotient will be recognized as numerator and denominator of 9/31. The next two pairs of numbers indicate the fractions 2/7 and 1/3, already known. These fractions are called convergents of 9/31.

The numbers in the second and third lines have an interesting property. Let us consider any two consecutive pairs of figures, for example $\frac{1}{3}$ and $\frac{2}{7}$. The products of the numbers forming opposite corners of the quadrangle $\begin{matrix}1 & 2\\ 3 & 7\end{matrix}$, are $1 \times 7 = 7$ and $2 \times 3 = 6$. The difference between these products is, in this and in any other case, ± 1. Two fractions a/b and c/d, for which $(ad - bc) = \pm 1$, are called conjugate. A symbol for $(ad - bc)$ is $\begin{vmatrix} a & c \\ b & d \end{vmatrix}$, which is called a determinant.

The error in replacing 9/31 by 2/7 is absolutely $2/7 - 9/31 = \frac{62 - 63}{7 \times 31} = -1/7 \times 1/31$; or related to 9/31, $-1/7 \times 1/31 \times 9/31 = -1/7 \times 1/31 \times 31/9 = -1/7 \times 1/9$.

In the same way, the error in replacing 9/31 by 1/3 is absolutely $1/3 - 9/31 = \frac{31 - 27}{3 \times 31} = 4/3 \times 1/31$; or related to 9/31, it is $+ 4/3 \times 1/31 \div 9/31 = + 4/3 \times 1/31 \times 31/9 = + 4/3 \times 1/9$.

This example shows a regularity in the errors which is characteristic of any case. The errors are alternately positive and negative; the absolute error is inversely proportional to the denominator of the exact fraction (31), whilst the error related to the exact fraction is inversely proportional to the numerator of that fraction (9).

The coefficients $-1/7$ and $+4/3$ by which 1/31 or 1/9 are multiplied to obtain the absolute or relative error respectively, can readily be found in a similar manner to that in which the convergents are found. Let us repeat the scheme, and place 0 and 1 in a fourth line in the last two columns, as follows:

		3	2	4	
1	0	1	2	9	
0	1	3	7	31	
			1	0	

Multiply the last quotient (4) by the number which stands in the fourth line in the next column to the left (1), and add the number in the fourth line which stands in the same column as the quotient (0); the result $(4 \times 1) + 0 = 4$, is placed to the left of 1.

If the same is done with the next quotient 2 we obtain as the next number in the fourth line, $(2 \times 4) + 1 = 9$.

(*Continued on page* 31)

An Electrical Dynamometer for the Direct Measurement of Mechanical Power, Torque and Speed for very High Shaft Speeds

By B. Eckert. (From *Report No. FKFS 10–1276/3 of the Institut für Kraftfahrwesen und Fahrzeugmotoren, Technische Hochschule, Stuttgart*, October, 1945, made available by courtesy of the Board of Trade, German Division, Technical Information and Documents Unit).

The exact determination of the mechanical power transmitted to or from a machine is important in very many cases, but offers considerable difficulties, especially at very high shaft speeds. The properties required of such a measuring device are: adaptability for the highest shaft speeds, direct measurement if possible, remote indication and recording, low maintenance, wide range of speed, torque and power, simple construction, and high accuracy. Most of the methods now in use are satisfactory only for speeds up to 3000 rpm. The difficulties arising in electrical methods are the transmission of the signal from the moving part by means of sliprings, and the required large diameter of the rotating parts. The apparatus described in the following, while avoiding these disadvantages, largely fulfils all the demands mentioned above.

Fig. 1.

The shaft A (Fig. 1), the power of which is to be measured, is fitted with two small a.c. generators D, at the points B and C. These generators have permanent magnet rotors. In the stator coils of both generators two e.m.f.'s, E_1 and E_2, will be induced. Depending on the relative torsion angle ψ, the e.m.f.'s will be out of phase by the angles φ, where $\varphi = p\,\psi$, $2p$ being the number of poles of the generators.

The difference between voltages U_1 and U_2 (Fig.2), with equal amplitudes U_{max}, results in an instantaneous value of the alternating voltage

$$U_0 = U_1 - U_2 = U_{max} \sin \omega t - U_{max} \sin (\omega t - \varphi)$$
$$= 2U_{max} \cos (\omega t - \varphi/2) \sin \varphi/2$$

and an effective value of the alternating voltage

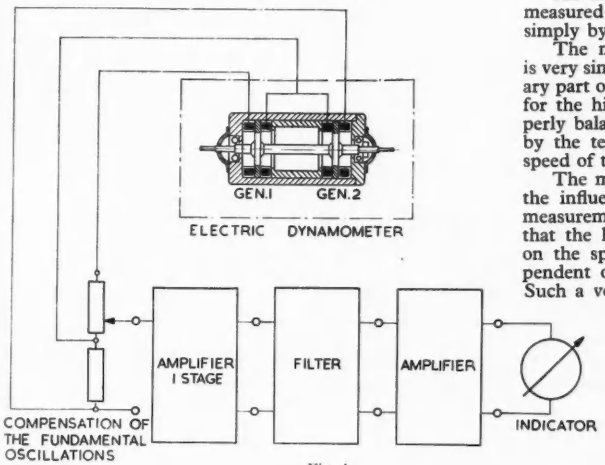


Fig. 4.

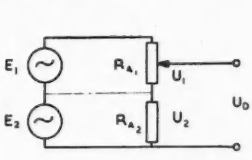


Fig. 2.

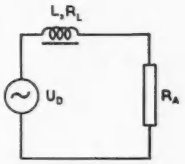


Fig. 3

$$U_{0\,eff} = [U_{max}\varphi/\sqrt{2}$$

considering that for small angles $\sin \varphi = \varphi$.

As $\varphi = p\ \psi$ it is possible to magnify the angular phase difference within certain limits by using generators with a large number of poles, an arrangement which in addition allows the measurement of rotary oscillations.

U_1, U_2 and U_{max} are proportional to the angular velocity ω. According to Hooke's law the torsion angle ψ is proportional to the torque M_d. It is, therefore,

$$U_{0\,eff} = k_1\,\omega\,k_2\,M_d\,p/\sqrt{2} = k\,M_d\,\omega = k\,N$$

Accordingly, the voltage $U_{0\,eff}$ is a direct measure of the mechanical power transmitted.

In addition, if it is required to measure the torque, the voltage $U_{0\,eff}$ has to be divided by a value proportional to the speed. This is done by applying $U_{0\,eff}$ to a circuit consisting of an induction coil (L, R_L) and an ohmic resistance R_A in series, (Fig. 3). The voltage drop across R_A, neglecting the ohmic resistance of the coil is:

$$U_{A\,eff} = U_{0\,eff} \frac{R_A}{\sqrt{R_A^2 + (\omega L)^2}} \approx \frac{U_{0\,eff}\,R_A}{\omega L} \approx \frac{k_N\,M_d\,\omega\,R_A}{\omega L}$$

or

$$U_{A\,eff} = k_M\,M_d$$

which means that $U_{A\,eff}$ is a direct measure of the torque M_d.

All three values, n, M_d and N, can, therefore, be measured by means of one set of measuring generators, simply by using a voltmeter and a selector switch.

The mechanical construction of the dynamometer is very simple. As the voltage is taken from the stationary part of the dynamometer, the apparatus can be used for the highest speeds. If the rotating parts are properly balanced, the limiting speed is solely determined by the tensile strength of the material or the critical speed of the shaft.

The main difficulty which had to be overcome was the influence of the harmonics which made accurate measurements impossible. It can be proved, however, that the harmonic factor is almost linearly dependent on the speed, so that a d.c. voltage also linearly dependent on the speed can be used for compensation. Such a voltage is available in both the generated voltages after rectification. Only an additional generator winding is needed for this compensation. Although this arrangement requires a complicated amplifier and a linear rectification, and although the compensation has to be readjusted for each new operating range, this kind of compensation is used on all the instruments now in existence.

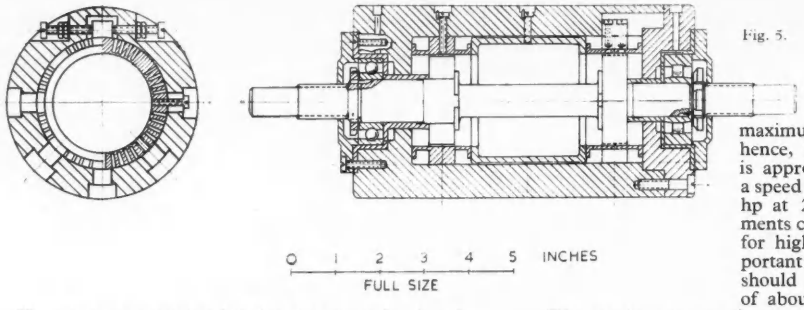


Fig. 5.

However, a new system is being at present developed where no special compensating winding is required. Instead of this, the generated voltages are cleared of all the harmonica by means of electric filters. The finally approved arrangement is shown in Fig. 4.

The structural design of the measuring element is shown in Fig. 5. This instrument was built for a maximum torque of 40 mkg; hence, the maximum power is approximately 1650 hp at a speed of 30000 rpm or 1100 hp at 20000 rpm. Instruments can, of course, be built for higher ratings. The important fact is that there should be a torsion angle of about 1 degree.

The maximum error due to temperature differences when measuring power is about ± 0·56 per cent for a temperature change of 50 C ; using special alloy steels, the error is about 0·7 per cent. The error due to temperature when measuring torque is ± 0·8 per cent for 50 C and, when reversing speed ± 0·22 per cent for 50 C.

U. S. A.

Precipitation of Smoke, Fog, or Dust Particles by Sonic Waves

By H. W. St. Clair, H. W. Danser and E. P. Neumann. (Condensed from two articles published in *Industrial and Engineering Chemistry*, Vol. 41, No. 11, November, 1949, pp. 2434-2442, 12 illustrations.)

It has been observed that smoke, fog and other dispersions of liquids or solids in gases are unstable and undergo spontaneous flocculation after a certain time, this being inversely proportional to the number of particles per unit volume. The only forces acting on the particles under these conditions are those molecular forces that produce Brownian movement. Under the influence of high frequency sound, however, new forces are brought into action which cause rapid agglomeration of smokes that would otherwise remain fairly stable for a long period. The behaviour of suspended particles under such conditions may be considered as attributable to a combination of co-vibrations of particles in the vibrating gas, attractive and repulsive forces between neighbouring particles, and radiation pressure.

Co-vibration of Suspended Particles. Because of the viscous reaction of the gas in which a particle is suspended, the particle will participate to a certain extent in the vibration of the gas. When the particles are very small or when the vibration frequency is low, the particles will vibrate with virtually the same amplitude as the gas. At higher frequencies the inertia of the suspended particles becomes relatively larger and, consequently, the relative amplitude of the particles become less, until a frequency is reached at which the particle will remain virtually stationary while the gas vibrates past it. In this range, particles of different sizes vibrate with different phases as well as different amplitudes. The relative amplitude or phase of a particle is determined by the product of the frequency and the square of the diameter, thus:

$$\frac{X_p}{X_g} = \frac{1}{\sqrt{1 + \left(\frac{\pi \rho f d^2}{9\mu}\right)^2}}, \text{ and } \phi = \tan^{-1} \frac{\pi \rho f d^2}{9\mu}$$

where X_p and X_g are the amplitudes of particle and gas respectively, ϕ is the difference in phase of gas and particle, ρ and d respectively the density and diameter of the particle and μ the viscosity of the gas.

At a frequency of 5000 cps water droplets less than 1 micron in diameter will vibrate with virtually the same amplitude as the gas, whereas particles 10 microns in diameter have an amplitude of only 5 per cent of that of the gas. If the frequency is increased to 25,000 cps, 1 micron droplets have an amplitude of about 90 per cent of that of the gas. The frequency must be increased to about 90,000 cps to reduce the relative amplitude of such droplets to one half. However, owing to the difference in phase, even when the relative amplitude of the droplet is only one half, the maximum relative velocity of the gas with respect to the droplet is nearly 87 per cent of what it would be if the particles remained stationary.

Attraction and Repulsion. The hydrodynamic forces of attraction and repulsion are effective only when two particles are separated by distances equal to a few particle diameters. They arise as a result of the constricted flow of the gas between two adjacent particles. These forces do not require vibration of the gas and would apply in principle to unidirectional gas flow. However, it is only when the gas is vibrating at a high frequency that high relative velocity can be maintained between a suspended particle and the gas surrounding it. If two spherical particles relatively close together and having their line of centres transverse to the direction of vibration are considered, the cross-sectional area through which the gas must flow may be considered as constricted in the region between the two particles. As a result there will be a slightly greater velocity of flow in this region. According to the well known Bernoulli principle there will be a drop in static pressure in this region, and the spheres will behave as though they were being attracted to each other. Conversely, there will be a sheltered zone on the leeward side of a particle so that particles having their line of centres in the direction of vibration will be repelled from each other. Consequently, the effect of the sound field on suspended particles is to give rise to repulsive forces between particles in the direction of vibration and to attractive forces in the transverse direction.

Being inversely proportional to the fourth power of the distance between centres, these forces will be important only when the particles are very close together. Hydrodynamic forces, as also the co-vibration

of particles, are by themselves inadequate to account for the increase in rate of coagulation, but they are important in increasing the effective particle diameter and in causing the formation of thin, wafer-like flocks made up of particles which cling together tenaciously and set themselves at right angles to the direction of vibration. In a stable standing wave field of plane waves, such flocks may reach a diameter of several centimetres.

Radiation Pressure. The effect of radiation pressure depends on the size of the surface relative to the wavelength of the sound, and on whether it is exerted against a large reflecting surface, or against a small obstacle suspended in a standing wave field. It is the latter case which is important in sonic agglomeration.

A spherical obstacle in a standing wave field is acted on by a force that urges it towards the antinode of the standing wave. The force is zero at the nodal and antinodal positions and reaches a maximum midway between. The maximum value of the force acting on a sphere of radius a is equal to

$$F_r = \frac{10}{3} \frac{\pi^2 a^2}{\lambda} \bar{E} = \frac{5\pi}{2\lambda} V \bar{E}$$

where λ is the wavelength, V the volume of the sphere and $\bar{E}$ the energy density. This relation applies to spheres, the diameter of which is small with respect to the wavelength. The radiation pressure of the sound field having an amplitude of 50 microns and a frequency of 20 kcps is sufficient to support a sphere having the density of water.

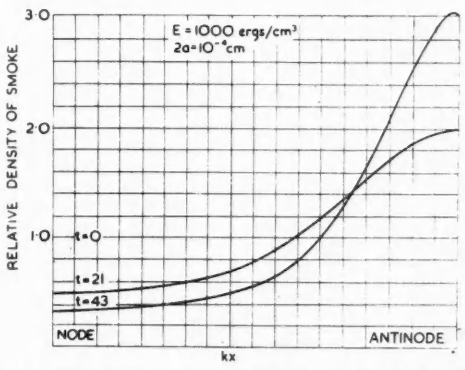


Fig. 1. **Rate of flocculation of ammonium chloride smoke at various sound intensities.**
Smoke concentration, 2mg/litre.

When a large number of suspended particles is subjected to radiation pressure in a standing wave, the particles will drift toward and become concentrated in the antinodal regions. The position for a particle under the influence of radiation pressure is described by:

$$x = \frac{1}{k} \tan^{-1} (\tan k x_0 e^{Bt})$$

where x_0 = position of particle at time $t = 0$; x = position of particle at time $t = t$; $k = 2\pi/\lambda$; $B = 20/9\ \pi^2 a^2 \bar{E}/\lambda^2 \gamma$; a = radius of particles; γ = viscosity of the gas. The progressive changes of concentration of particles initially distributed uniformly is shown in Fig. 1.

The effect of harmonics must, obviously, also be taken into account and in practice there will be, instead of a single antinodal region, a series of antinodal planes becoming progressively more closely spaced as the fundamental antinodal plane is approached. The change of concentration shown in Fig. 1 will, therefore, be occurring for each harmonic, and concentration at harmonic antinodes may be more effective than at the fundamental antinode. It is, in fact, probable that the rapidity of sonic agglomeration is due largely to the non-linear distortion of the sound field.

The described behaviour of suspended particles under the influence of radiation pressure is quite consistent with that observed during experiments. To give a more exact theoretical description of the behaviour, it will be necessary to take into account the hydrodynamic forces of attraction and repulsion between spheres subjected to radiation pressure. However, theoretical work in this field still needs to be done.

Speed of Flocculation. The rapidity of flocculation is determined by the acoustic energy density of the sound or the number of ergs of acoustic energy per cubic cm. The energy of the sound field may also be expressed in terms of intensity or watts of acoustic energy per cm². The energy density and intensity are related to the frequency and amplitude of vibration as follows:

$$E = 2\pi^2 \rho f^2 \xi^2$$
$$I = 2\pi^2 \rho c f^2 \xi^2 \times 10^{-7}$$

where: E = energy density, ergs cm³; I = intensity, watts/cm²; ρ = density of gas; f = frequency, cps; ξ = amplitude, cm.

Flocculation begins to be effective at an energy density of 50 ergs/cm³, but rapid agglomeration requires energies of more than 100 erg/cm³. Energy densities of several thousand erg/cm³ have been attained in the flocculating chamber. The corresponding acoustic intensity is of the order of several watts/cm². The amplitude required for 100 and 1000 ergs/cm³ at a frequency of 10 kcps is about 80 and 250 microns respectively. The energy required to support a water droplet against the force of gravity is about 400 ergs/cm³ at 10 kcps.

The essential elements required for sonic agglomeration of aerosols are a resonant enclosure and a sound generator capable of attaining sound intensities of the order of 1 watt/cm². When the enclosure is large with respect to the wavelength, its dimensions are not especially critical, for there will be many modes of vibration, and so, within certain limits, it will be resonant to a continuous range of frequencies. Further investigation is needed regarding the design of inlet and outlet ports that will transmit a minimum of high frequency sound energy, but will allow passage of a unidirectional flow of gases.

Other factors to be studied are the shapes of the enclosures to give the optimum standing wave pattern and other features that will minimise dissipation and radiation of acoustic energy.

The electromagnetic sound generator used in the experiments described was employed primarily for its

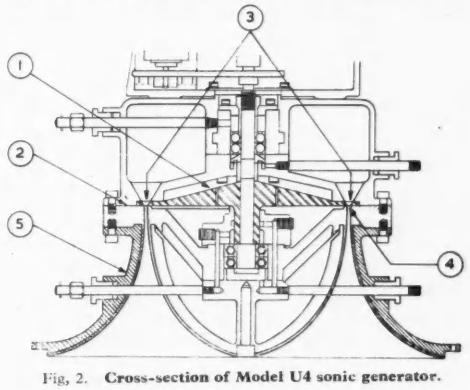


Fig. 2. **Cross-section of Model U4 sonic generator.**

advantage in experimental control and measurement. Generators operating on compressed air or gases offer a simpler and more practicable sound source for industrial application, and high frequency sirens as described in the following seem to be the most practicable sound sources available at present.

Industrial Sonic Agglomeration. If laboratory data are extrapolated to industrial-scale collection problems of 10,000 to 100,000 cubic feet per minute, a sound generator with an output of the order of 10 to 50 kW is needed. No means has yet been found that will permit economical construction of large-scale electronic type sound generators, and the jet type has a low efficiency. However, the recent development of an efficient siren type sound generator (Fig 2) makes possible an output of this order of magnitude. This generator consists of a rotor (1) facing a stator (2), with precision-matched ports (3) around the periphery of each. A compressed gas is passed through the ports of the rotor and then through those of the stator. As the rotor turns, alternatively opening and closing the ports of the stator, the gas flows out intermittently through the stator ports. An intense sound wave is thereby created at the interface (4), and is directed by an acoustic horn (5) from the generator. Intensity of the sound wave is governed by the pressure of the compressed gas, and the frequency by the speed at which the rotor turns. To govern the rotor speed, a variable speed motor may be used. About 225 cfm of gas compressed to 8 psi, is required to operate this generator.

Up to 3000 cfm of dust-laden gas may be processed by one such generator when installed in the manner shown in Fig. 3. Several such generators may be used in parallel. Larger models of sound generators have also been developed. Each has a gas-treating capacity of up to 50,000 cfm.

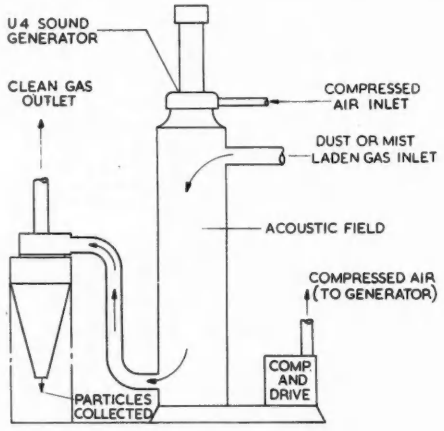


Fig. 3. **Sonic collection system installation.**

Any particular installation must reflect a balance between the three variables of sound intensity, exposure time and sound frequency. An example of this may be taken from an installation built for the collection of sulphuric acid fog from flue gases of a contact type sulphuric acid plant, (Fig. 4.). The flue gases leaving the sulphuric acid absorption tower enter a humidification chamber, where sulphur trioxide, passing through water sprays, is converted to sulphuric acid mist; the particles of the mist are believed to range from 05 to 5 microns in diameter. The gas stream carrying this mist measures 24,000 cfm at 125° F. It is introduced tangentially into the bottom of a cylindrical agglomeration tower, 8 ft in diameter and 35 ft high,

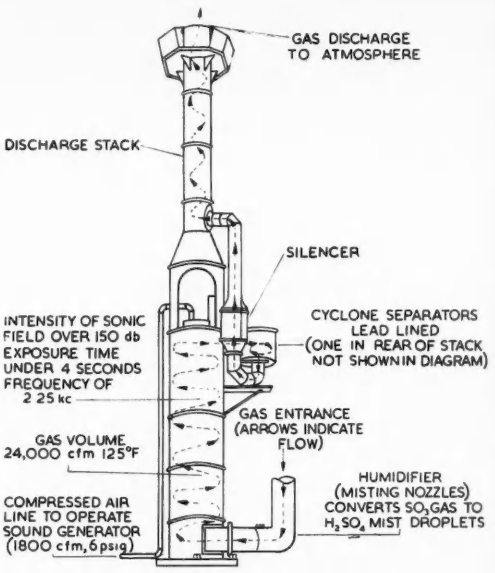

GAS DISCHARGE TO ATMOSPHERE
DISCHARGE STACK
SILENCER
INTENSITY OF SONIC FIELD OVER 150 db EXPOSURE TIME UNDER 4 SECONDS FREQUENCY OF 2 25 kc
CYCLONE SEPARATORS LEAD LINED (ONE IN REAR OF STACK NOT SHOWN IN DIAGRAM)
GAS ENTRANCE (ARROWS INDICATE FLOW)
GAS VOLUME 24,000 cfm 125°F
HUMIDIFIER (MISTING NOZZLES) CONVERTS SO_3 GAS TO H_2SO_4 MIST DROPLETS
COMPRESSED AIR LINE TO OPERATE SOUND GENERATOR (1800 cfm, 6 psig)

Fig. 4. **Flow diagram of acid fog collector.**

where it is treated and subsequently passed through cyclones to the atmosphere. When the sound generator is not operating, the acid fog particles pass vertically through the tower, entirely through the cyclones, and into the atmosphere. With the sound generator operating, however, a sound pressure field of over 150 decibels is produced throughout the tower. Operation of this installation showed that the gas needs to be exposed to the acoustic field for less than 4 seconds for the fine particles to be agglomerated to such size that over 90 per cent by weight of the acid may be removed from the gas stream, about half of the collection occurring on the inner walls of the tower, the remainder within the cyclones. The exit gases leaving the sonic collector then contain between 2 and 3 milligrams of sulphuric acid per cu ft.

Another installation was built for the sonic collection of soda ash fume from the flue gases leaving a recovery boiler in a paper mill. The gases enter an agglomeration tower and subsequently pass through cyclone separators for recovery of the agglomerates, the cleaned gas finally passing to the atmosphere. Gas flow rate measures about 50,000 cfm at 200 F. The fume particles leaving the furnace average less than 1 micron in diameter. Here again, a sound pressure field of high intensity is produced, to which the fine particles are exposed for less than 4 seconds. In such a paper mill installation, the value of the agglomerated material collected by the cyclones may return the cost of the investment in the sonic collector within a period ranging from 12 to 20 months.

In many cases the installed cost of a sonic collection system is much less than the cost of electrostatic collectors. The installed cost of industrial-scale sonic collection systems ranges downward to below 1 dollar per cu ft of installed capacity. Overall operating cost, including power plus operating and maintenance labour, is likewise low, ranging downward to below $0·0007 per 1,000 cu ft of gas treated. Other important points concerning this system are the absence of any fire hazard, independence of the electrical characteristics of the particles, the very wide range of gas temperatures that can be allowed, and the smallness of the particles that can be effectively treated.

A New High-Speed Diesel Engine

By G. MUSELIUS. (From *Teknisk Tidskrift*, Vol. 79, No. 17, April 23, 1949, pp. 311-314, 6 illustrations.)

THE Tampella Works, of Tammerfors, Finland, decided to make a diesel engine for the Finnish " Sisu " lorry in 1943. New workshops were set up, and the first series-built engine was produced in 1946.

The first work on experimental diesel engines for lorries and buses was begun in 1936. In order to reduce the amount of development work and to obtain sufficient data for comparison, a Mercedes-Benz four-stroke cycle diesel engine, type OM. 65, was acquired. This is a four-cylinder in-line engine with pre-combustion chambers, and a compression ratio of 18 : 1. Glow plugs are used for starting, and the engine develops 65 bhp at 2000 rpm (or 13·5 bhp/litre), with a bmep of 6·55 kg/cm² (93·2 psi) and a maximum torque of 25 kgm (180·83 lb-in.). Total weight without the gearbox is 460 kg (1014 lb).

The Tampella Co. decided to build a four-cylinder engine, somewhat similar to the Mercedes-Benz, and also a 6-cylinder unit with the same cylinder design for buses. The engines were to be simple in operation and maintenance and their cost prices were required to be not more than 20 per cent higher than those of the cheapest imported engines of comparable power. Licencing commitments were to be avoided. In respect of size, weight, capacity, operational economy, running qualities and manoeuvrability, the engines were to be able to stand comparison with the foreign engines most sold in Finland, namely the Mercedes Benz and the Büssing N.A.G. Complicated designs incorporating starting aids such as glow plugs, variable compression chambers, special injection equipment, and special piston designs or mass balancing arrangements were to be avoided as far as possible.

A cast cylinder block integral with the crankcase of high-grade perlitic iron was therefore adopted as the cheapest type for manufacture, with cylinders having a bore of 115 mm (4·526 in.) and a 140 mm (5·512 in.) stroke, giving a swept volume of 1454 cm³ (88·726 cu in.) per cylinder. The crankshaft was designed with large journals, circular webs, and without balance weights. The crankpin diameter was so chosen as to allow the connecting rods to be removed through the cylinder bores. The middle bearing of the crankshaft was made shorter than the others, to enable large cylinder bores to be used without increasing the engine length. All the journal surfaces were hardened and supported by bronze bearing shells with white metal linings, as bearings of this type had given the best results under operating conditions prevailing in Finland. It was also found that the cast cylinder blocks were very robust, in spite of the relatively short and light pistons used.

In the meantime the brake tests on the Mercedes Benz were continued. The engine had developed 65 bhp at 2000 rpm, but its power decreased after running for short periods, as the engine warmed up excessively. The fuel consumption of the stationary engine was 208-216 g/hp-hr (0·459-0·476 lb/hp-hr) at full load.

The question of the combustion process was becoming urgent, since more limitations were being placed on the combustion chamber as the other engine details were being determined. Direct injection without various air swirl arrangements was out of the question. Pre-combustion chambers involving complications during engine starting had to be avoided, as well as the high compression ratio of nearly 18 : 1 of the Mercedes Benz engine. Attention was, therefore, directed to the *after-chamber arrangement*, in which the fuel is directly injected into the main chamber and blown into an after-chamber. The air blast is obtained partly from two air cells, situated symmetrically and at a certain angle above and below the injection nozzle, and partly by partial combustion of pre-injected fuel in the after-chamber during the compression stroke. The aim was to obtain, by means of this air blast, a finely distributed and rapidly igniting spray extending over the entire pancake-shaped portion of the combustion chamber formed by the cylinder head and the piston. The arrangement, shown in Fig. 1, is so designed that the cells are closed when the piston is at the top dead centre position, and uncovered immediately afterwards, so that the gases in the cells will flow out again and mix with the spray directed towards the after-chamber, the gas jets being of equal strength.

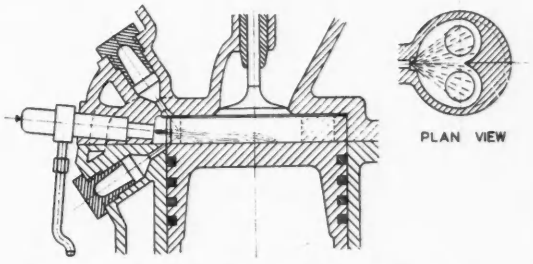


Fig. 1. **First sketch of combustion chamber of the Tampella diesel engine.**

The combustion chamber design was subsequently modified, and the final design is similar in principle to the arrangement shown in Fig. 2, with both air cells situated in the cylinder head. The chamber used is of the conical type, with the spray directed at an angle into the pancake-shaped after-chambers situated in a shallow recess of the piston crown. By combining the two after-chambers on one side, and designing them around the conical spray it was possible to improve the combustion process. A high-grade steel insert was used for temperature regulation; this insert maintains a higher temperature at increased engine speeds, and contributes to reducing the ignition delay, thus rendering any external form of ignition control either partly or entirely unnecessary. Patents have been obtained for these various designs.

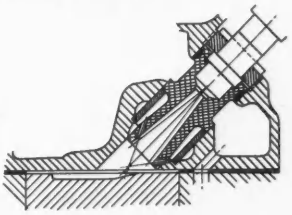


Fig. 2. **Modified combustion chamber design.**

The new type of combustion chamber was tried out on the Mercedes Benz previously mentioned, after modifying the pistons and cylinder heads. The tests showed that the system was reliable in operation, and capable of starting without glow plugs at room temperatures, whereas this was not possible with the original engine. The power output was 58·5 bhp at 2000 rpm, or about 90 per cent of the maximum output of the Mercedes engine, corresponding to a fuel consumption of approximately 235 g/bhp-hr (0·518lb/bhp-hr), which is comparable with that of the Büssing type engines. The arrangement was also tested on a Studebaker truck, and showed similar results.

A marine version of the new design was then first developed. This water-cooled 6-cylinder 4-stroke cycle engine is known as the Tampella A.6. It has a capacity of 8·73 litres (532·74 cu in.), a bore of 115 mm (4·52 in.), a stroke of 140 mm (5·512 in.), a compression ratio of 17 : 1, and develops 88 bhp at 1500 rpm, and 113 bhp at 2000 rpm. The propeller is geared down to 900 rpm maximum speed. The inlet and exhaust valves have a diameter of 40 mm (1·575 in.) and the timing is as follows:—inlet opening 3° before TDC, inlet closing 40° after BDC, exhaust opening 47° before BDC, exhaust closing 13° after TDC. The engine has also been produced as a four-cylinder unit, and the latest designs include various improvements.

BELGIUM

A General Combustion Diagram Applicable to any Fuel

By M. VÉRON. (From *Revue Universelle des Mines*, 9th Series, Vol. 5, No. 5, May, 1949, pp. 150-170, 13 illustrations.)

ANALYSES of fuel and exhaust or flue gases are often not followed up to best advantage, since the necessary calculations are rather tedious. The combustion diagrams should obviate the necessity of such calculations and afford an easy means of

(1) determining excess or deficiency of air from two of the following three constituents of the flue gases: CO_2, CO, O_2;
(2) checking the analysis of the flue gases from the determination of the third constituent;
(3) identifying the fuel from measurement of the three flue gas constituents;
(4) determining the volume of exhaust gas per unit of fuel weight and loss of heat per unit of fuel weight for a given gas temperature, and
(5) predicting gas evolution for a given set of conditions. Most diagrams do not give complete answers without calculations. and, therefore, a new and general diagram developed by M. Pigrais is described in this paper.

I. SYMBOLS AND FORMULAE

All volumes are referred to 0° C and 760 mm Hg pressure.

V_F = actual total dry flue or exhaust gas volume per unit of weight of a given, known, fuel (combustible constituents only included in weight determination);

V_A = actual volume of air supplied per unit weight of fuel;

V_f = exhaust gas volume, per unit weight of fuel, which would be obtained by complete combustion with sufficiency of air;

V_a = air volume needed for complete combustion, with sufficiency of air, of one unit weight of the given fuel;

$+e = (V_A - V_a)/V_a$ = excess (positive) or deficiency (negative) of air for actual combustion.

Let v_{CO} = volume of CO present in the actual exhaust gas volume V_F, then since $CO + {}^1/_2 O_2 = CO_2$, i.e., $1^1/_2$ parts by volume of separate gases correspond to 1 part by volume of the completely burnt gas, we obtain

$$V_F = V_f + e\,V_a + \frac{1}{2} v_{CO}$$

and $$\beta = v_{CO}/V_F = \frac{v_{CO}}{V_f + e\,V_a + 0{\cdot}5\,v_{CO}} = \text{CO-content}$$

of actual exhaust gas.

Furthermore, let v_{O_2} = volume of free O_2 present in volume V_F. Presence of free O_2 is due (a) to the O_2 in the true amount of excess air and (b) to the O_2 which has not combined with the CO-gases according to the formula given above. Hence,

$$v_{O_2} = \frac{20{\cdot}8}{100} e\,V_a + \frac{1}{2} v_{CO}$$

and $$\omega = v_{O_2}/V_F = \frac{0{\cdot}208\,e\,V_a + 0{\cdot}5\,v_{CO}}{V_f + e\,V_a + 0{\cdot}5\,v_{CO}} = \text{free } O_2\text{-content}$$

of actual exhaust gas.

Finally, let v_{CO_2} = volume of $CO_2 + SO_2$ present in volume V_F, and V_{CO_2} = volume of $CO_2 + SO_2$ which would be present in the theoretical exhaust gas volume V_f. Then $\alpha_0 = V_{CO_2}/V_f = CO_2 + SO_2$ content of exhaust gas of a given known fuel completely burnt with a sufficiency of air and $v_{CO_2} = \alpha_0 V_f - v_{CO}$ since the sum $v_{CO} + v_{CO_2}$ must be constant for unit weight of a given pure fuel, whether burnt completely or incompletely. Hence

$$\alpha = v_{CO_2}/V_F = \frac{\alpha_0 V_f - v_{CO}}{V_f + e\,V_a + 0{\cdot}5\,v_{CO}} = CO_2 + SO_2$$

content of actual exhaust gas.

Introducing $x = e\,V_a/V_f$ and $y = v_{CO}/V_f$ we obtain the characteristic equations of the Pigrais Diagrams:

$$O_2\text{-content: } \omega = \frac{0{\cdot}208\,x + y/2}{1 + x + y/2} \quad .. \quad .. \quad (1)$$

$$CO\text{-content: } \beta = \frac{y}{1 + x + y/2} \quad .. \quad .. \quad (2)$$

$$CO_2\text{-content: } \alpha = \frac{\alpha_0 - y}{1 + x + y/2} \quad .. \quad .. \quad (3)$$

x and y are both independent of the type of fuel used, and only α_0, which characterises the complete combustion with a sufficiency of air, depends on the fuel used. Hence, ω and β are also independent of the type of fuel; only α varies with a change of fuel characteristics. Similarly, the ratio V_F/V_f is independent of the type of fuel, since

$$v = V_F/V_f = 1 + x + y/2 \quad .. \quad .. \quad (4)$$

The loss of heat due to the temperature t of the exhaust gases is

$$Q_s = c\,t\,V_F = (1 + x + y/2)\,c\,t\,V_f,$$

where c is the mean specific heat, between the temperatures 0 and t in °C, of a unit volume of the gases. c does not vary appreciably with the composition or the temperature (within limits) of the gases. We can, therefore, deduce a specific ratio of the heat losses, q_s, which is again independent of the type of fuel used:

$$q_s = \frac{Q_s}{c\,t\,V_f} = 1 + x + y/2 = v \quad .. \quad (5)$$

q_c is the ratio of heat losses, due to temperature, from a volume V_F to those from a corresponding volume v_F at the same temperature. If the variation of c with temperature has to be considered, it is easy to correct the result obtained from the diagram. The heating value of CO-gas is 3066 kcal/m³ (346 BThU per cu ft referred to 0° C, 760 mm Hg); the loss of heat due to incomplete combustion is, therefore,

$$Q_l = 3066\, v_{CO} = 3066\, y\, V_f$$

and the specific ratio q_l, which is independent of the type of fuel used, is

$$q_l = \frac{Q_l}{3066\, V_f} = y \qquad \ldots \qquad \ldots \qquad (6)$$

q_l is the ratio of heat losses, due to incomplete combustion of the actual exhaust gas to those of a volume V_F of pure CO-gas in the exhaust.

Eqs. (1) to (3) can also be enlarged to take account of any free H_2-gas present in the exhaust or flue. Since $H_2 + {}^1/_2\ O_2 = H_2O$, which condenses and is not measured in the dry gas analysis, the amount of O_2 supplied when H_2-gas is present in the exhaust must be

$$v_{O_2} = \frac{20{\cdot}8}{100}\, e\, V_a + \frac{1}{2}\, v_{CO} + \frac{1}{2}\, v_{H_2} = 0{\cdot}208\, e\, V_a + 0{\cdot}5\,(1 + z)\, v_{CO},$$

where the ratio $z = v_{H_2} : v_{CO}$ can usually be assumed to be constant for a given combustion process. The volume V_F increases by $3/2\ v_{H_2}$ due to the presence of $1\frac{1}{2}$ parts by volume of uncombined H_2 and O_2 gases, so that

$$V_F = V_f + e\, V_a + \tfrac{1}{2}\, v_{CO} + \tfrac{3}{2}\, v_{H_2} = V_f + e\, V_a + 0{\cdot}5\,(1 + 3z)\, v_{CO}.$$

If free hydrogen is present in the exhaust or flue, eqs. (1) to (3) thus become transformed to

$$O_2\text{-content:}\ \omega = \frac{0{\cdot}208\, x + (1 + z)\, y/2}{1 + x + (1 + 3\, z)\, y/2} \qquad \ldots \qquad (7)$$

$$CO\text{-content:}\ \beta = \frac{y}{1 + x + (1 + 3\, z)\, y/2} \qquad \ldots \qquad (8)$$

$$CO_2\text{-content:}\ \alpha = \frac{\alpha_0 - y}{1 + x + (1 + 3\, z)\, y/2} \qquad \ldots \qquad (9)$$

to which must be added

$$H_2\text{-content:}\ \eta = z\, \beta = \frac{z\, y}{1 + x + (1 + 3\, z)\, y/2} \qquad (10)$$

If steam is included in the analysis of humid exhaust gases, $1\frac{1}{2}$ parts by volume of separate $H_2 + O_2$ correspond to 1 part by volume of steam after ideal combustion, and we obtain

$$V_F = V_f + e\, V_a + \frac{1}{2}\, v_{CO} + \frac{1}{2}\, v_{H_2} = [1 + x + (1 + z)\, y/2]\, V_f,$$

where V_f now includes the steam directly generated from the water content of fuel and air. It then follows that

$$\omega' = \frac{0{\cdot}208\, x + (1 + z)\, y/2}{1 + x + (1 + z)\, y/2} \qquad \ldots \qquad (11)$$

$$\eta' + \beta' = \frac{(1 + z)\, y}{1 + x + (1 + z)\, y/2} \qquad \ldots \qquad (12)$$

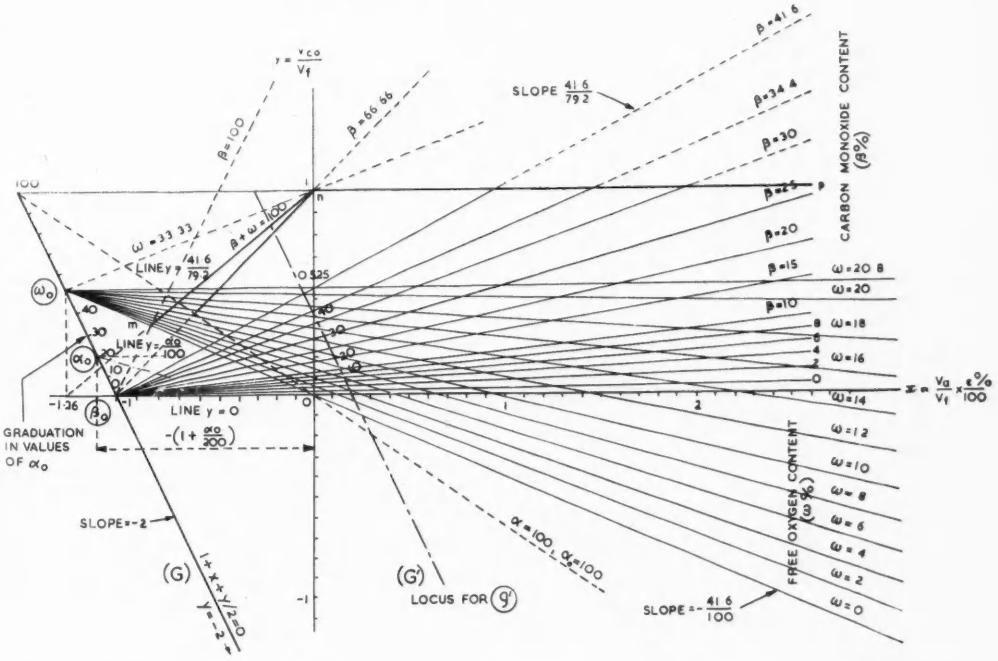


Fig. 1. **Pigrais diagram for dry exhaust gases without free hydrogen (Background).**
Lines of constant excess or deficiency of air (x), of constant free oxygen (ω), and constant free carbon-monoxide (β) percentages. Theoretically possible values must lie within area $xOmnp$.

II. DEVELOPMENT OF DIAGRAM AND APPLICATIONS

All the foregoing equations can conveniently be represented as straight lines in an x-y plane. Lines of constant ω and constant β form families of concurrent straight lines, the ω-lines converging to a point ω_0 found from the condition of eq. (1)

$$0{\cdot}208\,x + y/2 = 0 = 1 + x - y/2, \text{ or } x = -1{\cdot}26,$$
$$y = 0{\cdot}525,$$

the β-lines converging at β_0 found from eq. (2), i.e.,

$$y = 0 = 1 + x - y/2, \text{ or } x = -1, y = 0.$$

Values of ω may vary between 0 and 20·8 per cent. The line $\omega = 0$ passes through the origin and has the slope $-41{\cdot}6/100$; the line $\omega = 20{\cdot}8$ per cent is horizontal. Values of β may vary between 0 and an upper value which is certainly below 41·6 per cent. The line $\beta = 0$ is represented by the abscissa, $\beta = 41{\cdot}6$ per cent intersects the y-axis at $y = 0{\cdot}525$ and has the slope $+41{\cdot}6/79{\cdot}2$. These two families of lines are fixed in the x-y plane, since ω and β are functions of x and y only. They are drawn on the background of the diagram (Fig. 1).

Lines of constant α also form a family of straight lines converging to a point α_0 found from eq. (3)

$$\alpha_0 - y = 0 = 1 + x - y/2, \text{ or } x = -(1 - \alpha_0/2),$$
$$y = \alpha_0.$$

α_0 lies on line (G) connecting ω_0 and β_0 (Fig. 1). The value of α may vary between 0 and α_0. The line $\alpha = 0$ is horizontal, and $\alpha = \alpha_0$ always passes through the origin. The slope of any α-line can be derived from eq. (3) as follows:—

$$\frac{dy}{dx} = -\frac{\alpha}{1 + \alpha/2}$$

The α-lines are, therefore, also fixed once α_0 is given (Fig. 2); the point α_0, however, changes with the composition of the fuel and moves along the line $1 + x - y/2 = 0$. The whole α-family of lines moves with α_0 by pure translation. For pure carbon, $\alpha_0 = 20{\cdot}8$ per cent ($x = -1{\cdot}1$, $y = 0{\cdot}2$ approx.). For solid and liquid fuels, α_0 will be below 20·8 per cent; for gaseous fuel it may reach higher values, e.g., 34·4 per cent for pure CO-gas; for fuels which contain all the oxygen needed for combustion it may reach 100 per cent. For $\alpha_0 = 0$, α_0 coincides with β_0; for $\alpha_0 = 52{\cdot}5$ per cent, α_0 coincides with ω_0. Line (G) of Fig. 1 may, therefore, be graduated in percentages of α_0 and the position of the α-family of lines then adjusted to the required position of α_0.

The complete diagram, which, by a simple adjustment and without any re-tracing is applicable to any type of fuel, thus consists of a background graph with the β and ω-family of lines and the line (G) graduated in percentages of α_0 (Fig. 1). A transparent slide, on which is drawn the α-family of lines (Fig. 2), is arranged to slide over this background in a direction parallel to line (G). Point α_0 of the slide moves directly along line (G) and is adjusted to the α_0-percentage characteristic of the type of fuel used. The whole diagram refers to combustion of one unit of weight of any fuel. The following general rules can immediately be deduced:

(1) On the diagram, each point of intersection of two lines of different families represents one type, and one type only, of exhaust (or flue) gas. The percentage of the constituent represented by the third family of lines follows automatically if the slide is adjusted to the given type of fuel. The three percentages plus nitrogen add up to 100.

(2) To each point of the diagram is co-ordinated one unique value of x. The exhaust gas represented by that point can only have been evolved by combustion with one definite amount of excess or deficiency of air.

(3) A given excess or deficiency of air may lead to evolution of an infinite variety of exhaust gases, all characterised by points on the same vertical line.

(4) Incomplete combustion with a deficiency of air (to the left of the origin) may, under certain circumstances, lead to a higher O_2-percentage in the exhaust than does incomplete combustion with an excess of air.

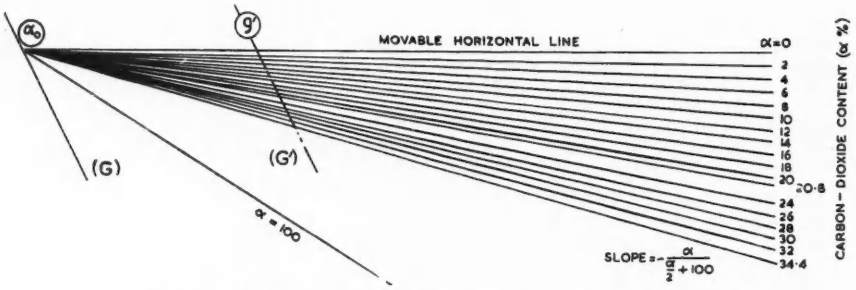


Fig. 2. **Pigrais diagram for dry exhaust gases without free hydrogen (Slide).**
Lines of constant carbon-dioxide percentages (α).

The mode of procedure is as follows: From the dry exhaust or flue gas analysis of two gas constituents, the point of intersection of the corresponding diagram lines can be found by interpolation where required.

(A) If the CO and O_2-percentages are measured, this point is found on the background graph itself and the type of fuel is irrelevant.

(B) If the CO and CO_2, or the O_2 and CO_2, percentages are measured, the slide must be adjusted to the α_0-value of the fuel used and the point of intersection can then be found.

(C) From the abscissa x of the point of intersection, the excess or deficiency of air as well as the volume of air actually supplied can immediately be deduced:

$$e = \frac{V_f}{V_a} x \text{ and } V_A = V_a + x\,V_f.$$

V_a and V_f are usually known for the type of fuel used, e.g., from the fuel analysis. $V_a \simeq V_f$ for coal. *Method (A) thus permits direct determination of the excess of air without the need for any special estimate of fuel composition.*

(D) If two gas constituents are determined from the exhaust gas analysis and the α_0-value of the fuel is known, the diagram offers a check on the determination of the third gas constituent. If results from analysis and from the intersection of lines on the diagram do not coincide; (a) the analysis may be faulty; (b) the gas may contain H_2 (see below); (c) the diagram may have been drawn incorrectly; (d) a different fuel

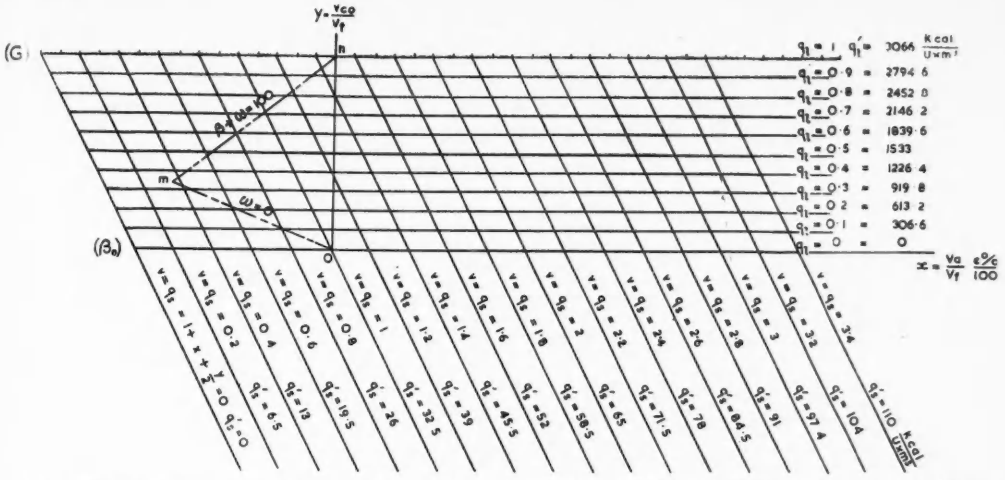


Fig. 3. **Pigrais diagram for dry exhaust gases without free hydrogen (Additional background or second slide).** Lines of constant exhaust gas volume (v), of constant heat losses due to exhaust gas temperature (q_s) and incomplete combustion (q_l). Theoretically possible values lie to the right of lines *Omn*.

may have been used.

(E) If the three gas constituents are determined from dry exhaust gas analysis, the characteristic α_0-value of the fuel may be obtained from the corresponding position of the slide and the nature of the fuel may be deduced. In practice, solid and liquid fuels are always uniquely determined by their α_0-value, and gaseous fuels usually within the range of a given application. This determination is obviously only approximate.

Changes in the composition of an exhaust gas can sometimes be foreseen from the diagram.

(1) If a fuel is gradually burned under a constant supply of air, the representative point of its exhaust gases moves vertically downwards, since $v_{CO} = y\ V_f$ decreases whilst x remains constant. With an excess of air, combustion finally goes over into complete combustion with $\beta = 0$; with a deficiency of air, the representative point finally reaches the line $\omega = 0$ when all the available oxygen is being used up.

(2) If an exhaust gas is diluted with air at a temperature which is too low for further combustion, the representative diagram point of the mixture moves horizontally towards the right, since v_{CO} does not change whilst the excess of air e (or x) increases.

III. EXTENSION OF DIAGRAM

The values v, q_s, q_l (eqs. (4) to (6)) are functions of x and y only. The lines of constant v and q_s are identical; they are parallel to Line (G) of Fig. 1. The lines of constant q_l are horizontal, and the values of q_l coincide with the ordinate values y. All three variables are fixed in the x-y plane, and their lines can, therefore, be directly superimposed on the background graph, Fig. 1. In order not to overload this graph, the author prefers to inscribe them on a separate second slide, which, however, is stationary with respect to the background. (Fig. 3). Apart from the q_s and q_l scales, certain q_s' and q_l' scales are indicated in Fig. 3, where $q_s' = Q_s/V_f = c\ t\ q_s$ [kcal/m³ of the corresponding "neutral" exhaust gases]

is given for $t = 100$ °C and $c = 0{\cdot}325$ kcal/m³, °C, and

where $q_l' = Q_l/V_f = 3066\ q_l$ [kcal/m³],

both scales being referred to unit weight U of the fuel used.

Once the point of intersection on the diagram has been obtained from the dry gas analysis of two exhaust gas constituents, the ratios v, q_s, q_l, and q_s', q_l' can be read directly off the completed diagram, and the following important characteristic values can be found by simple deduction:

$V_F = v\ V_f$ [m³ (0 °C, 760 mm Hg) per unit fuel weight];

$Q_s = c\ t\ q_s\ V_f = q_s'\ V_f$ [kcal heat loss per unit fuel weight];

$Q_l = 3066\ q_l\ V_f = q_l'\ V_f$ [kcal heat loss per unit fuel weight].

V_f is again assumed to be known in advance. V_F represents the volume of the dry exhaust gases, exclusive of any steam. Its value is both independent of any steam in the exhaust and of any content in minerals of the fuel; it refers to a pure and dry fuel and remains valid for all other fuels which differ in water and mineral contents only. If the value q_s' is read off the diagram (Fig. 3), correction must be made for temperatures other than 100 °C by multiplication with a factor $t/100$. If the temperature differs very much from 100 °C, the specific heat c must also be corrected.

The Pigrais Diagram can be further extended to yield more specialised characteristics of the exhaust gases.

IV. PRACTICAL CONSIDERATIONS AND AUTOMATIC RECORDING ARRANGEMENTS

In theory, combustion can only take place under conditions represented by points above the lines $\beta = 0$ (abscissa) and $\omega = 0$, and below the lines $\beta + \omega = 100$ per cent and $y = 1$, i.e., within the area $xOmnp$ of Figs. 1 and 2. In practice, however, the relevant portion of the diagram is well within the limits $+2 > x > -0{\cdot}3$ and $0{\cdot}525 > y > 0$ and can, therefore, be drawn on a larger scale for greater accuracy. Line (G) falls outside this portion of the diagram, and a parallel line (G') should be drawn, graduated in values of α_0 and repeated on the movable slide with the α-family. The slide can then be adjusted to the required value of α_0 by placing line (G') of the slide on top of line (G') of the background and letting the horizontal line $\alpha = 0$ of the slide intersect (G') of the background at the required graduation value for α_0. The accuracy of reading is greatest for the α and the ω-lines; if the characteristic value α_0 of the fuel is accurately known, it is, therefore, better to operate with the slide than with the background alone. For frequent usage, the transparent slide can be made of perspex and the back-

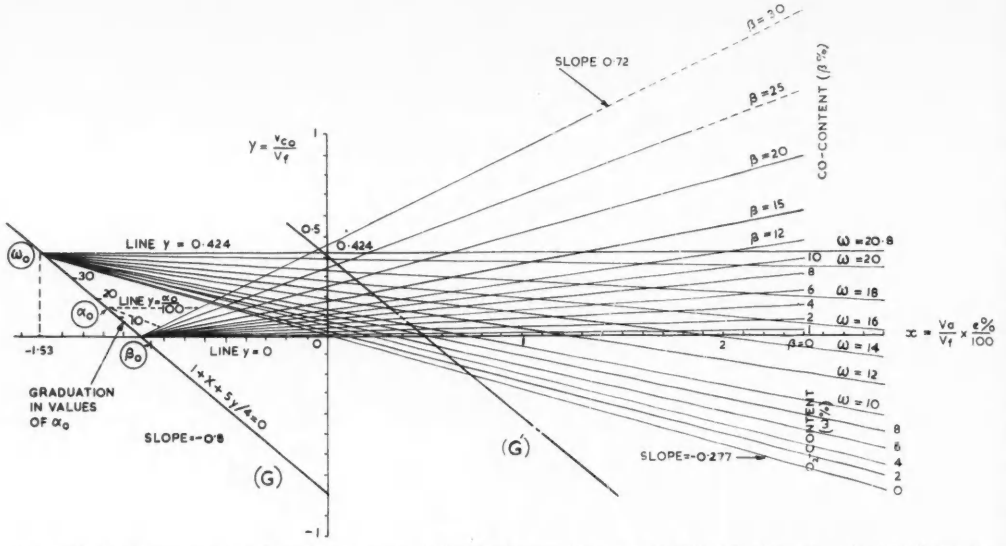


Fig. 4. **Pigrais stereogram for dry exhaust gases with free hydrogen. Section along Plane H_2 CO $z = 1/2$. (Background).**

ground provided with guides which control the movements of the slide.

Assume that an automatic O_2-analyser has a pointer turning about point ω_0 of a Pigrais diagram background so that its angular position indicates the O_2-content ω of the exhaust or flue gases, and that an automatic CO-analyser has a pointer turning similarly about point β_0 and indicating the CO-content β of the gases. The point of intersection of the two pointers then represents the analysed exhaust gas and, with a suitable diagram background (Fig. 3 suitably enlarged) the excess of air

wires. It is, however, more convenient, and sufficiently accurate, if only certain sections of this stereogram are given in diagram form, e.g., sections along the planes $z = 0, 1/4, 1/2, 3/4, 1$. Higher values of z are only met with in exceptional cases, and intermediate values can be considered by interpolation. Once the H_2-content and z-value have been determined, the corresponding sectional diagram is again applicable to all types of fuel. Figs. 4 and 5 show the sectional diagram for $z = 1/2$; exhaust gases of carburetter engines can usually be represented by points in that plane.

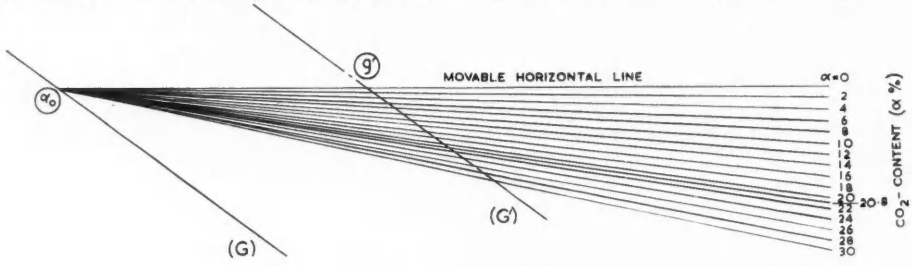


Fig. 5. **Pigrais stereogram for dry exhaust gases with free hydrogen. Section along plane H_2 CO $= z = 1/2$. (Slide).**

(vertical lines) and the heat losses (oblique and horizontal lines) can be directly read off the background. Unfortunately, automatic O_2 analysers are seldom used in Europe, but their use is spreading in the U.S.A., and the advantages of a direct reading of the excess of air and the heat losses should outweigh considerations of initial cost. *Automatic control devices can be attached for automatic adjustment of air supply to the best advantage and integrating recorders may indicate heat losses and savings over certain periods of time and provide a powerful incentive to fuel economy.*

V. EXTENSION OF DIAGRAM TO HYDROGEN-CARRYING EXHAUST GASES

If the radio z in eqs. (7) to (10) is considered to be variable, then these equations form the basis of a three-dimensional stereogram which could be made up with

If the humid exhaust gases are analysed with their steam content, the "background diagram" (Fig. 1) can be used separately to represent eqs. (11) and (12), provided:

(a) the theoretical gas volume V_f includes the steam generated from water contained in fuel and air;

(b) the diagram ordinates represent the combined CO + H_2 content, i.e., $(v_{CO} + v_{H_2})/V_f = (1 + z)\,y$;

(c) the β-family of lines represents the total amount of unburnt and incompletely burnt constituents in the exhaust, i.e., $(v_{CO} + v_{H_2})/V_F = \eta' + \beta'$.

No stereogram need be used unless the CO_2 content is also required to be known.

Should the dry exhaust gases contain appreciable quantities of other combustible constituents, e.g., hydrocarbons, sulphides, etc., the diagram can still be adapted if not more than two such constituents are present.

New Method for Checking the Airgaps of Motors for Mining Installations

By N. A. KIKLEVICH. (From *Promyshlennaya Energetika*, No. 9, 1948, pp. 7-9, 7 illustrations.)

IN all induction motors, the airgap varies to a certain extent along the circumference of the rotor. Whereas on most types of motors a check of the gap variation can be made easily enough by means of feelers, this is much more difficult on flame-proof motors. According to Russian standards, these motors must have no holes except those required for the bolts holding together various parts of the motor, and the passages for the supply leads. It is not even permissible to drill holes for feelers, which could subsequently be plugged by screws. Investigations have shown that, owing to this difficulty, the irregularity of the airgap reaches 25 per cent on some new motors, and often is as high as 30-40 per cent after an overhaul. Thus, the inadequacy of airgap inspection has been the cause of frequent motor failures in mining installations, and it was in order to overcome this difficulty that the dynamic method described hereafter was developed for the measurement of airgap irregularities.

The principle of the arrangement is illustrated in Fig. 1. The equipment consists essentially of a laminated iron-core pick-up, a milliammeter, and a rectifier circuit. The pick-up is placed on the circumference of the active iron of the rotating motor. The leakage flux affecting the iron-core pick-up is then inversely proportional to the instantaneous value of the airgap nearest to it and the ammeter indicates the variation in flux.

As a result of extensive tests, the following empirical formula was determined, and was found to represent with sufficient accuracy the indication of the instrument as a function of airgap irregularity:—

$$\beta = (1 + 0{\cdot}83\ \psi) / (1 - 0{\cdot}83\ \psi)$$

where $\beta = \alpha_{max}/\alpha_{min}$ = ratio of the maximum and minimum deflections of the ammeter needle when the pick-up is moved to different positions around the motor, and $\psi = \epsilon/\delta_n$ = ratio of the eccentricity ϵ to the nominal length δ_n of the airgap; this latter ratio is a measure of the risk of fouling of the stator by the rotor. The variation of β as determined by the above formula is shown in Fig. 2.

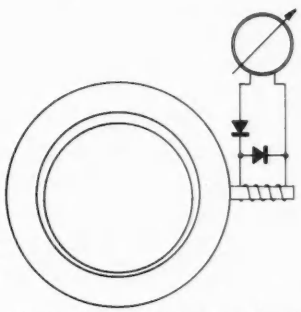


Fig. 1. **Pick-up arrangement for the measurement of rotor eccentricity.**

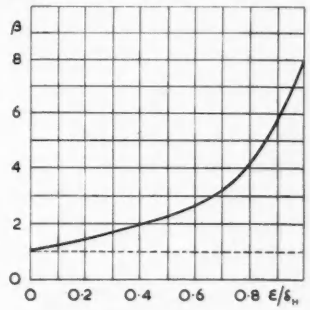


Fig. 2. **Curve showing the indication of the measuring instrument as a function of the irregularity of the airgap.**

Fig. 3 shows the results obtained on a 16 kW induction motor running at 1450 rpm. The measurements were made in three different planes perpendicular to the motor axis, after taking a series of check readings on the stationary motor by means of feelers for which holes were drilled. The higher readings of the measuring instrument can be ascribed to the additional eccentricity of the rotor shaft when the motor is rotating.

In motors with a stator core covered by a frame, the eddy currents in the frame completely damp out the leakage flux at the normal frequency of 50 cps. On such motors, measurements can be made using a low supply frequency of 0·5 to 1·0 cps. A voltage of approximately 3-5 volts is required. Such a supply can be obtained from the rotor of a slip ring induction motor. The measuring instruments should have ranges of 0·05-0·1 mA and 4-10 mV.

It can be shown by a simple calculation that no fouling of the rotor can occur if $\epsilon/\delta_n < 0{\cdot}4$-$0{\cdot}5$. This is the maximum permissible value for motors after overhaul; for new motors the ratio ϵ/δ_n must not exceed 0·2.

Generally, more accurate results are obtained by means of this method than when feelers are used, particularly since feelers can only be employed on stationary machines and thus take no Account of any bending of the shaft due to asymmetrical magnetic pull.

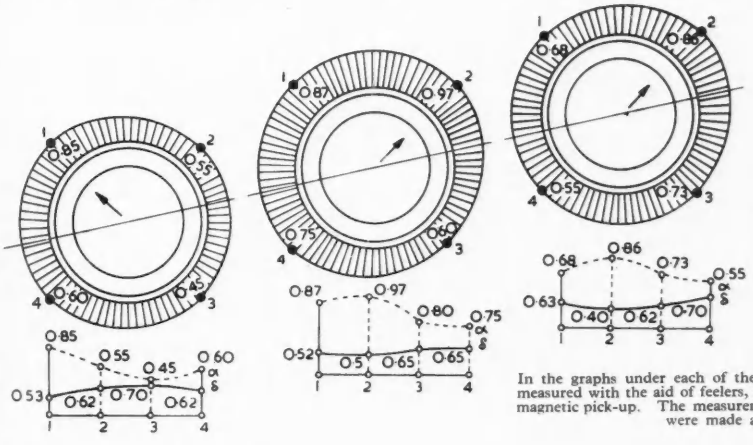


Fig. 3.

Comparison of results obtained with the magnetic pick-up and with feelers. Measurements made in three different planes along the rotor axis. The arrows indicate the directions of maximum eccentricity.

In the graphs under each of the figures, δ represents the airgap measured with the aid of feelers, and α the gap measured with the magnetic pick-up. The measurements with the magnetic pick-up were made at zero load.

DESIGN TRENDS ANI TH

OF MACHINE TOOL

BY TIB

NON-STANDARD KNEE-AND-COLUMN MILLING MACHINES

THE wide diversity of milling machines makes a hard-and-fast classification difficult, if not impossible, and, therefore, in the preceding paper we have adopted a classification to suit our convenience for the present purpose. The demarcation between the various types of milling machines has been determined by the visual aspect, and the classification adopted has to some extent restricted the selection of machines described. For most engineering purposes, such a classification may be quite wrong and superficial; in our case, it is thought to be instructive, as it puts emphasis on the inter-relation between form and function. It is hoped that this attitude toward design analysis is similar to, if not identical with, the industrial designer's viewpoint and is also helpful to those machine designers who are keen to visualize preliminary designs in terms of appearance. There is an increasing number of manufacturers who endeavour to train their engineering designers with this in mind. While only existing designs

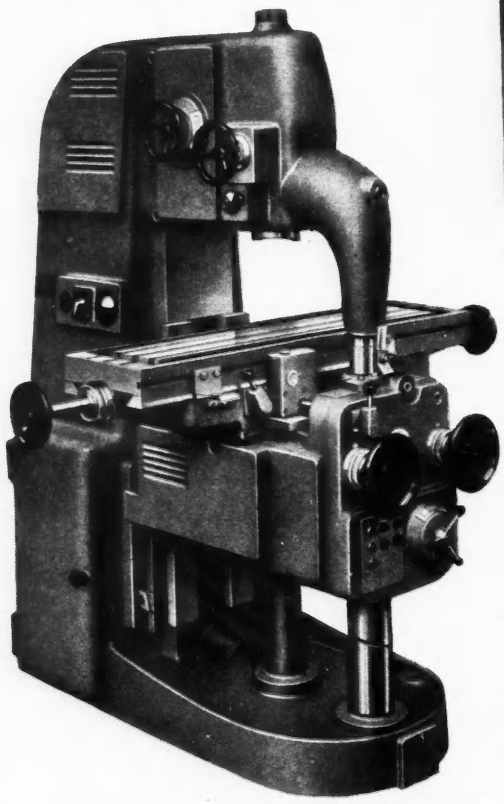


Fig. 76. **Vertical milling machine, type VS100 (Rigid, Ltd.)**

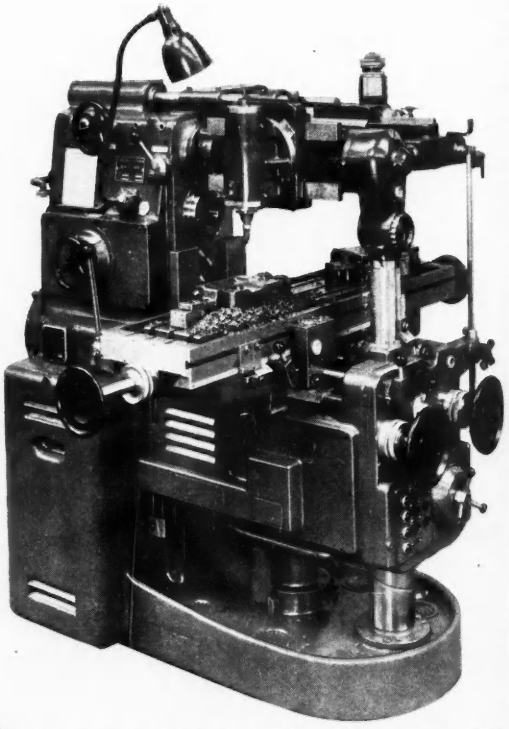


Fig. 77. **Horizontal hydro-copying milling machine S100 (Rigid, Ltd.)**

can be illustrated here, in which functional improvements and lower manufacturing costs have not always been related (but if so, not fully related) to possible improvements in appearance, the leading designs of tomorrow will certainly be those in which plain utility will play a fundamental part in the development of the basic form with due consideration given to the aesthetic factors. Thus, under the heading " non-standard knee-and-column machines," a great variety of " types " of milling machines will be found, in which identity of form has been lost.

So we come to deal with what could be termed the " closed frame " milling machine. In Fig. 76 a vertical milling machine is shown, which is characterised by the outer stay for increased rigidity. Its horizontal counterpart is the Rigid S100, shown in Fig. 77. Here the overarm is replaced by a cross-rail carrying slides for a vertical head milling attachment, and an outer column provides greater rigidity than do braces. This Swiss machine is of the hydro-copying type. The principles of milling are not fundamentally different from the principle applied to copy turning, and will not be dealt with here in detail, as tracer-controlled machining has been described in a previous paper in this series. It is also taken for granted that the readers will interpret

THE STYLE

BY TIBOR HAAS, A.M.I.MECH.E., A.F.R.AE.S.

MILLING AND GRINDING MACHINES PART II

the writer's previous analysis of machines in the sense that if points of merit of the VS100 and S100 were to be listed, these would be evaluated as very good examples of contemporary machine tool design.

The "Miniflex" universal milling machine, Fig. 78, is another "closed frame" machine. It mainly differs from those usually employed in that steel is used for the construction of the frame. This method of construction was chosen in view of the great rigidity of this material, which, in comparison with cast iron, is about 2½ times as great for the same dimensions. For the same rigidity, therefore, there is a considerable saving in material. Of course, in addition to the strength and rigidity obtainable with minimum use of material, a certain mass is also necessary, particularly in milling machines; this is in order to prevent vibrations, which may occur where constructions are too light, because of the intermittent forces acting on the cutter teeth. To achieve this aim, the Swiss "Miniflex" steel frame is tightly filled with concrete. Iron cramps are welded to the inner walls in order to anchor the concrete core firmly to the steel.

In the case of such construction the steel framework alone possesses the requisite strength and rigidity. The concrete acts, in addition, as a mass for damping vibrations. Also, the anchorage provided between the steel and the concrete results in further stiffening, which is perhaps not really necessary but is nevertheless advantageous, as has been demonstrated by measurements made before and after inserting the concrete. Cutting speeds up to 1312 fpm and feeds up to 39 ipm, were adopted.

Together with the infinitely variable control of the speeds and feeds, their wide ranges form an essential feature of this milling machine. Attention is also drawn to the patented connection between outer stay and cross-rail. Under the action of the cutting pressures the joints close. This is a remarkable constructional feature.

This machine is suitable for the surface milling of long workpieces. From the aesthetic viewpoint, an asymmetric form is excellently balanced by the size and location of solid disc control wheels. From other aesthetic aspects, this machine has all the attributes of good design.

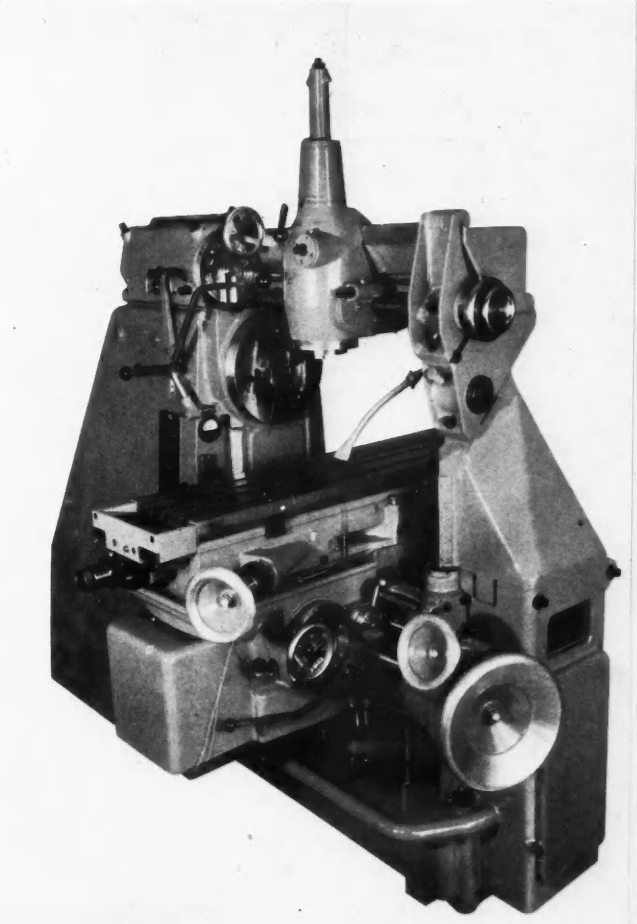


Fig. 78. **Universal milling machine "Miniflex."**

With ram-type milling machines, such as those made by the Van Norman Machine Tool Company, Springfield, Mass., Fig. 79 and 80, the cutter head, which is mounted on a sliding ram, permits the throat distance to be increased or reduced so that the spindle can be closely coupled to the column for maximum rigidity.

The overarm is also a ram with dove-tail, bearing on the main ram overarm slides. It provides rigid outboard support for horizontal milling and the required attachments. The overarm is solidly locked at front and rear of the ram by means of clamp-type binders.

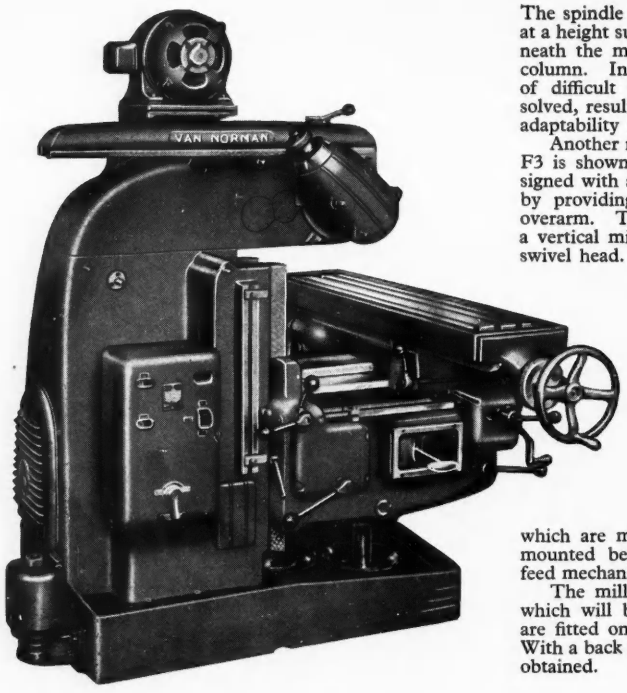


Fig. 79. **Van Norman ram-type milling machine No. 26.**
(Cutter head side; ram in outer position, overarm withdrawn).

The spindle drive motor is mounted on top of the ram at a height sufficient to allow the overarm to pass underneath the motor. The feed motor is enclosed in the column. In this universal milling machine, a number of difficult design problems have been successfully solved, resulting in rigidity, convenience of control and adaptability combined with modern appearance.

Another ram-type milling machine, the Swiss Aciera F3 is shown in Fig. 81. This machine has been designed with a view to increasing its field of application, by providing numerous attachments in place of the overarm. These attachments include, among others, a vertical milling head and a slotting attachment with swivel head. The expensive and heavy universal table has been dispensed with in this design, in which there is no "knee" in the conventional sense. Instead, the sliding surface of the longitudinal slide is in the vertical plane bearing on the column, this making for a rigid table. There is no transverse table motion, but the table is inclinable out of the horizontal plane, swivelling 30° — 0 — 45° and tilting 30° either side

The Adcock & Shipley duplex horizontal milling machine shown in Fig. 82 consists of a base carrying at either end a box-section column, on which are mounted the milling heads. The knee is mounted between the two columns and carries the feed mechanism for operating the table.

The milling heads are of the "unit-type design," which will be dealt with later in some detail. They are fitted on to Vee slides at the top of the columns. With a back gear, a total range of eight spindle speeds is obtained.

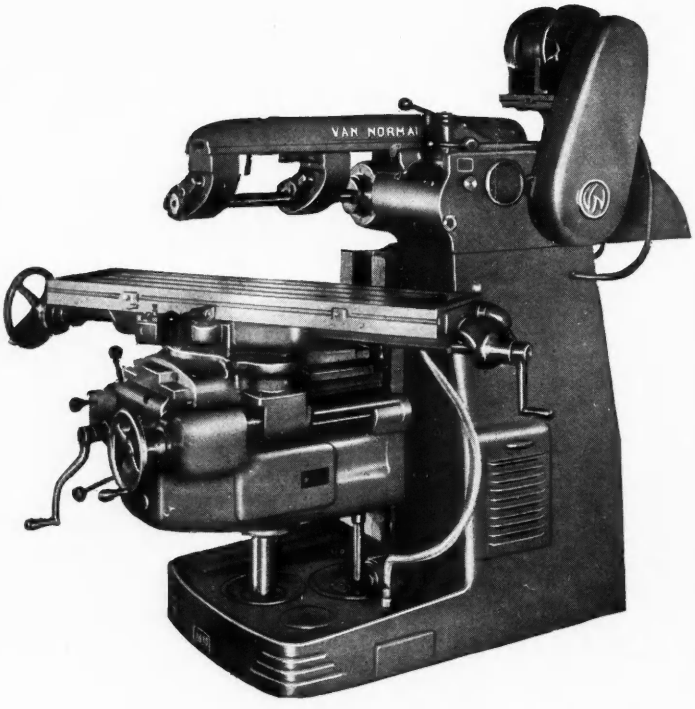


Fig. 80. **Van Norman ram-type milling machine No. 26.**
(Ram withdrawn, overarm in outer position fitted with arbor supports).

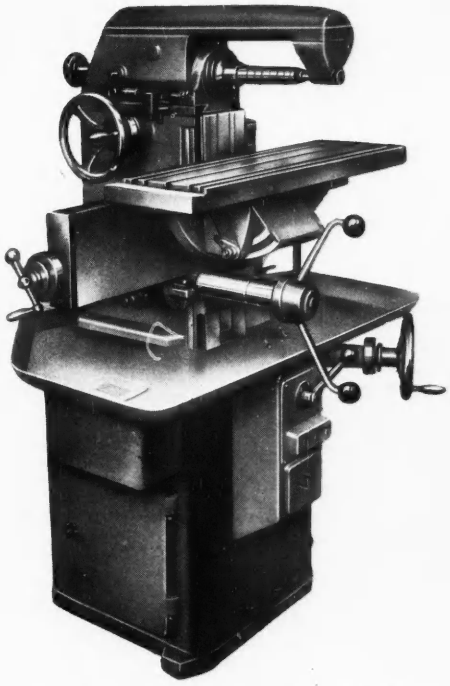


Fig. 81. **Aciera ram-type milling machine F3 (Aciera Ltd., Le Locle, Switzerland).**

The table feed mechanism is of the automatic cycle type. One movement of the control lever causes the following sequence of operations to be carried out automatically:—1. Rapid approach of the work to the cutters. 2. Change to cut feed rate. 3. Rapid return to loading position after cut has been completed. 4. Table will stop automatically in loading position for unloading, loading, and repeat of the cycle.

For lack of space, a number of milling machine types, such as, e.g., rotary millers of the drum type and of the rotary-table type, must be omitted from this survey. However, an unusual departure from the rotary-table machine, the rotary-head milling machine will be illustrated here, as it is a " knee-and-column " machine (Fig. 83). The vertical spindle may be offset from the centre of the head, and in combination with a revolving table attachment, intricate radial cam work can be produced without the use of a pattern or template.

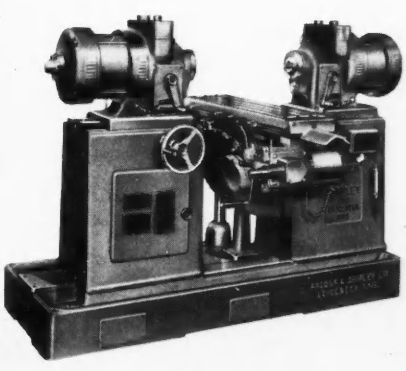


Fig. 82. **Adcock & Shipley duplex horizontal milling machine.**

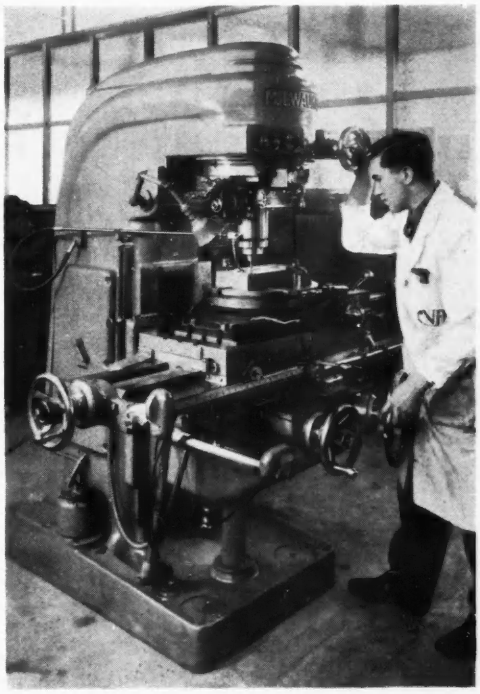


Fig. 83. **Kearney & Trecker rotary-head milling machine.**

BED-TYPE MILLING MACHINES

Known also as fixed-bed or manufacturing or production milling machines, these are designed for efficient production work rather than general or universal purposes. Inherent rigidity is obtained by having a fixed bed forming a base, on which the other members of the machine operate. The fixed bed is provided with slides for longitudinal table motion only. These machines have an upright, on which the vertically adjustable spindle head is mounted. The duplex type has, of course, two opposed uprights with vertically adjustable spindles. Further characteristics of this type of miller will be discussed with reference to individual makes.

Fig. 84 shows the Kent-Owens No. 2-20 hydraulic milling machine as a well-designed representative example of this class of machine. There is not so much of what the industrial designer calls " design content " in the bed-type of machine, as compared with, say, the knee-and-column type of horizontal miller. It is more the strict utility and simplicity that can make this class of machine a good-appearance job. In Fig. 84 this is brought out clearly. The base, with toe space for the operator, fully encloses the hydraulic pump, the spindle motor and the feed motor. The large chip and coolant trough and the robust brace give symmetry to the machine. Both the upright for the spindle housing

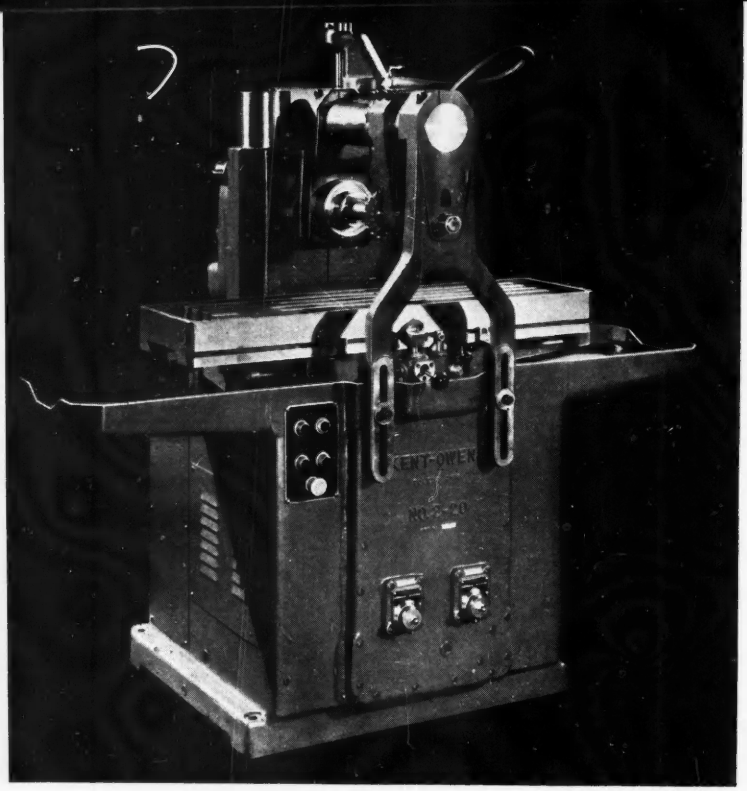


Fig. 84. **Kent-Owens No. 2-20 bed type milling machine.**

and the overarm are cylindrical. The fully automatic cycle is shown in Fig. 85. The table can be fed or rapid-traversed in either direction, automatically shifted from rapid traverse to feed in either direction, and automatically reversed at both ends of the stroke. It may be automatically stopped at any desired point in its travel. Five dogs—two rapid traverse to feed, two reverse, and one stop dog—are standard equipment. The machine can be equipped with either a one-way or two-way positive stop with dwell. With this arrangement, which is used for precision depth milling, the work is fed into the cutter to a fixed positive stop. It dwells there momentarily while the cut is cleaned out and the spring in the tools and work is relieved, and then automatically reverses out of the cut. This feature permits of performing one operation at one end of the table and a different operation at the other end. Each direction of table travel has a separate feed rate control dial, each dial being adjusted independently of the other. These control dials can be seen in Fig. 84 placed on the front cover of the base. The control panel contains five controls, the top left one starting the spindle drive motor; the top right control is the spindle reverse switch. The lower left control starts the hydraulic pump motor for table travel; the lower right one starts the coolant pump. The mushroom-head button at the centre lower end of the panel is for stopping all motors. The left-hand ball lever between the brace fork starts and stops the table movement; the one at the right is a table direction and rate lever. Its position indicates rapid traverse left, feed left, feed right and rapid traverse right.

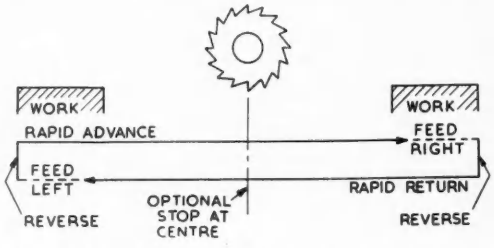


Fig. 85. **Automatic hydraulic table cycle on the Kent-Owens milling machine No. 2-20.**

Production requirements often dictate that several surfaces must be milled simultaneously. For this reason, the Sundstrand Machine Tool Company, Rockford, Ill. provide their standard "Rigidmil" with special heads to replace the standard milling head.

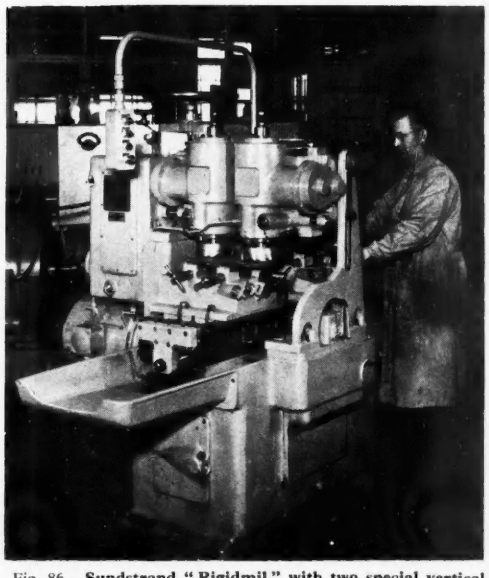


Fig. 86. **Sundstrand "Rigidmil" with two special vertical milling heads.**

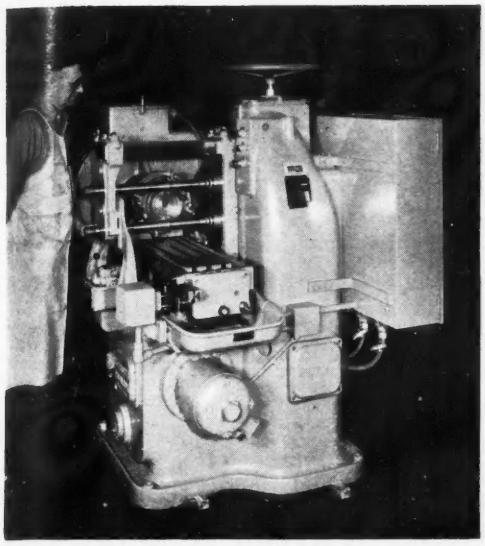


Fig. 87. **Sundstrand "Rigidmil" with special two-spindle horizontal milling head.**

Thus, only the heads are special to suit more complicated work, while the basic machine design is unaltered and the cost of the equipment kept to a minimum. In Fig. 86 a standard "Rigidmil" is shown, which has two special single-spindle vertical heads mounted on a cross-rail. The table holds two fixtures, one at each end. The operator is seen loading at one end, while automatic cycle milling takes place at the opposite end. Thus, no time is lost through loading and production is increased. Each spindle mills one pad on the workpiece, and the heads are adjustable on the cross-rail to facilitate the handling of different sizes of work. Another example of a mass-production job is shown in Fig. 87, that is, the milling of slots in a type bar segment. In this case, the standard head is replaced by a special two-spindle horizontal head. Mounted on the machine table is a special automatic index base, to which is attached a work-holding fixture holding one workpiece. By using a two-spindle head, two diametrically situated slots are milled with each cycle of the table until all slots are milled.

A German example of a bed-type machine, the Hürxthal FH surface milling machine is shown (Fig. 88), made by the firm of Hürxthal, Remscheid. It is of very simple but robust construction; it has a single-lever control and only one-directional rapid power traverse. The 4 hp spindle drive motor is flanged to the spindle housing; the feed drive is a closed unit, which, together with its 1 hp flanged motor, can be removed through an opening in the base. The outer stay, supporting the overarm, is of rigid construction.

The Swiss double-slot milling machine Reishauer type DLF is primarily intended for cutting slots, and is to a great extent automatic (Fig. 89). Idle time is limited to the changing of the workpiece. An electro-hydraulic control system is provided, and accurate and constant depth of the slot over its whole length can be automatically obtained. By virtue of the fact that there is a fixed bed and that the milling heads are mounted on "knees" bearing on either side of the base, a completely symmetrical layout is obtained, while the milling heads can be adjusted to different heights for the milling of different slots at the same time. Furthermore, it is possible to machine slots of different lengths in one workpiece during the same working process. This machine affords an interesting comparison with that illustrated in Fig. 82.

In the past few years, attention has been given in Britain[18, 19] to the application of fabricated steel construction to various machine tools, especially during the War, when the rapid manufacture of special single-purpose machine tools was imperative. The knee-and-column type standard milling machines are usually too complicated, so that fabricated construction could not compete economically with casting. However, the bed-type milling machine lends itself well to fabrication. From the standpoint of appearance design, fabrication judiciously applied has many attractive points. As an example, the Cooke and Ferguson production milling machine described in F. Koenigsberger's book[19] is illustrated here by courtesy of its publishers (Fig. 90). In this machine fabrication has not been used indis-

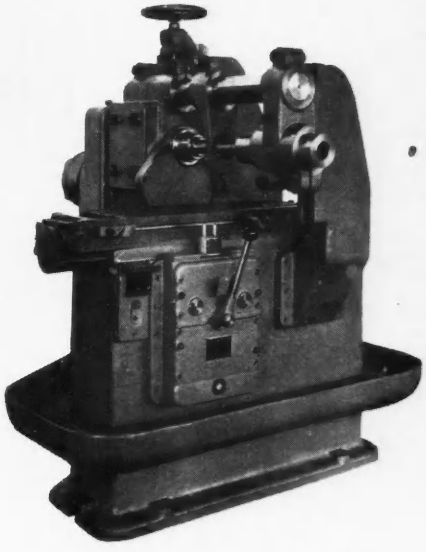


Fig. 88. **Hürxthal surface milling machine, type FH.**

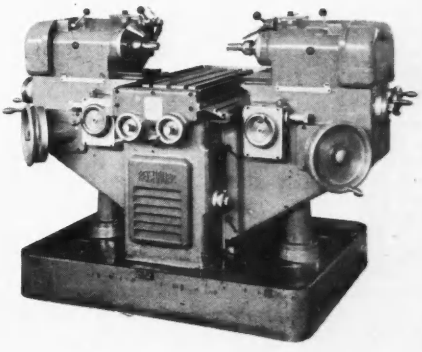


Fig. 89. **Reishauer double-slot milling machine, type DLF.**

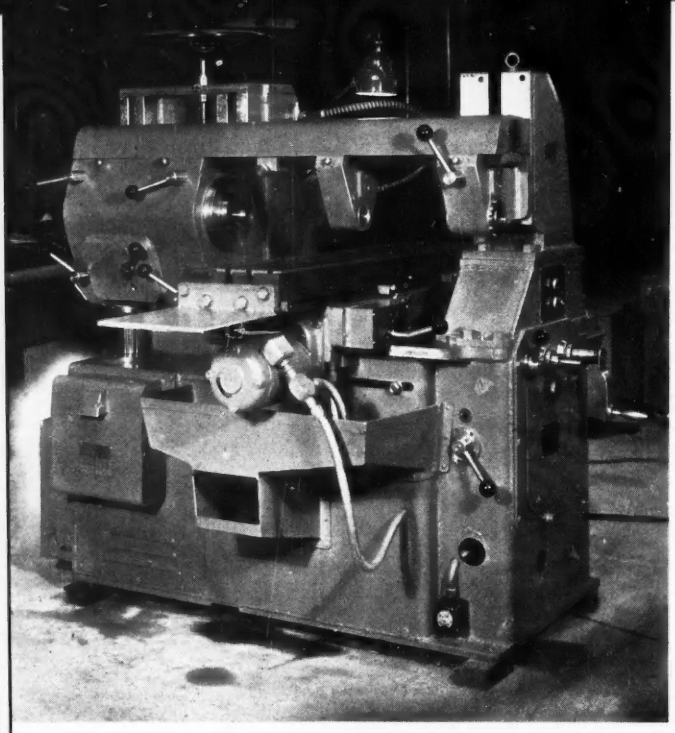


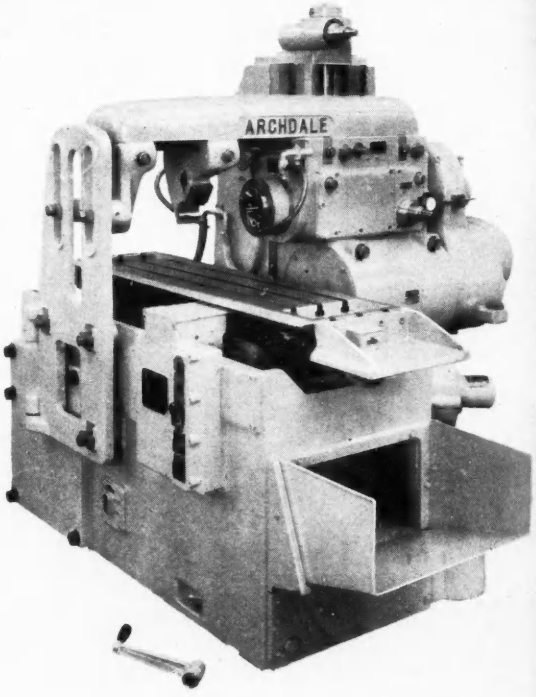
Fig. 90. (left) **Production milling machine (Cooke & Ferguson Ltd., Manchester).**

Fig. 91. (below) **Manufacturing milling machine (James Archdale and Co., Ltd., Birmingham).**

criminately, but has been adopted only where it has been considered most suitable for the purpose. Thus, fabricated construction has been used for the base, the upright, the outer stay, the spindle housing and the overarm, whilst the bed is a casting. This is a good example of design for welding, leading to a simplification of line and shape by the minimum use of raw materials. The base of bed-type machines lends itself especially to fabrication, and is found in a number of makes.

Figs. 91 and 92 show Archdale bed-type millers of the single-head and duplex type respectively. It will be noted that in both cases the milling heads are the same. They are of unit construction, to the characteristics and advantages of which we shall refer later. At this point these two machines are shown because they represent standard British designs of great merit both from the functional and appearance points of view. They are built with two different table widths and two lengths of traverse for each table width. The drive to the spindle, the head of which is adjustable vertically on a heavy box-section upright, is derived from a motor carried in the head, through spur and helical gears mounted on short shafts, and incorporates slip gear change. A complete set of speed gears comprises five extra pairs of gears per head. The bed incorporates feed and quick traverse drives by individual motors, the traverse being controlled by adjustable dogs on the side of the table operating switches in a control unit on the base. This unit

(*Continued on page* 32.)



CLASSIFIED ABSTRACTS

Numerous important abstracts which, for lack of space, cannot be published in our main editorial columns, are regularly included in condensed form in this section. Subscribers may obtain photostat copies of all original articles at cost.

FLOW OF FLUIDS

New Primary Element for Fluid Flow Measurement

(From *Energy, U.S.A.*, Vol. 11, No. 5, September-October, 1949, p. 5, 1 illustration.)

SEVERAL advantages over the primary elements in current use are claimed for a new primary element manufactured by the Bethlehem Foundry and Machine Company. Among these is greater simplicity in construction and operation arising from the short length of the tube (normally less than two pipe diameters) and its freedom from straight run limitations in regard to pipe bends and elbows. Greater economy is secured through the negligible resistance to flow of the tube, which reduces loss of head. Greater range, higher accuracy and simplified metering of gases and vapours are other advantages of the new element.

The flow tube consists essentially of a short tube equipped with two groups of pressure nozzles around the inner periphery—one group pointing upstream, the other downstream. These nozzle groups are connected by common pressure rings, from which connections are made to the high and low side of a standard flow meter. When the tube is in operation, a total head equal to the static head plus the velocity head is impressed on the nozzle pointing upstream. On the nozzles pointing downstream, a total head equal to static minus some component of velocity head is impressed. The differential head impressed on the meter is the difference between these two heads.

ORE TREATMENT

Dephosphorization of Iron Ore

By C. G. GRANSTRÖM. (From *Jernkontorets Annaler, Sweden*, Vol. 133, No. 9, 1949, pp. 323-367, 14 illustrations).

THE procedure of dephosphorization of iron ore by leaching with acids was suggested as far back as 1897 in a patent by G. A. GRANSTRÖM. The problem, however, was not closely investigated until 1937-40. Laboratory experiments and tests in a small experimental plant were then made, and among other results it was observed that phosphorus was precipitated in the product if hydrochloric acid was used as a solution agent in the extraction.

In 1941 the problem was taken up at the Grängesberg Export Ore Field, and favourable results were obtained with nitric acid. An experimental plant was built, in which highly concentrated iron ore pulp containing about 0·060 per cent P is treated with nitric acid, and a dephosphorized pulp is produced, containing more than 71 per cent Fe and below 0·010 per cent P. The consumption of acid, however, was rather high.

Since 1945 investigations have also been made by a Research Committee of Jernkontoret in close contact with the work at Grängesberg, and interesting results have been obtained concerning the influence of the size and character of the ore grains.

Based on the experience obtained, a new full-size plant has been built at Grängesberg for an annual production of 30,000 tons of dephosphorized iron ore concentrates. The plant has just been started, and the results seem to be very promising.

The Grängesberg dephosphorization method is characterized by the use of nitric acid as a solution agent and by the limited percentage of water in the extraction pulp. It is believed that this method will ensure the supply of pure iron ore for the production of sponge iron in Sweden, although more experience must be gathered with regard to the treatment of other ores than those from the Grängesberg mines.

POWER PLANT ENGINEERING

The Sun Power Scheme of the French National Research Centre

By J. LABADIÉ. (From *Elektrizitätsverwertung, Switzerland*, No. 9, 1949/50, pp. 185-189, 4 illustrations.)

While all energy utilized by industry is derived—indirectly—in one way or another, from the sun, the problem of direct utilization of the sun's radiant energy with a reasonable efficiency has hitherto remained unsolved.

An area of 108 sq ft within the tropics receives an amount of radiant energy equivalent to 1 hp for 8 hours per day all the year round. A number of sun power plants are in operation in Australia, Egypt and Mexico, with long steel tubes in the focal line of parabolic cylinder mirrors serving as boilers producing low-pressure steam for driving a steam engine. The efficiency of these plants is very low, the first cost and maintenance expenses are comparatively high.

The scientists of the French National Research Centre have recently succeeded in utilizing the sun's rays for obtaining the highest temperatures ever reached in a laboratory and are now proceeding to catch the sun's radiant energy not only at very high temperatures but also in large quantities.

Modern physicists apply the "ideal black body,"

CHANGE WHEEL GEARING

(*Continued from page* 12)

Similarly, the next figure to the left in the fourth line is $(3 \times 9) + 4 = 31$.

The fractions formed by the numbers in the fourth and third lines are the required coefficients of the errors, hereinafter referred to as "error coefficients," by which the fractions 1/31 and 1/9 are multiplied to obtain the absolute and relative errors respectively. It is merely necessary to enter a plus and a minus sign alternately, starting with + in the column of the convergent 1/0. The final scheme is then

			3	2	4
1	0	1	2	9	
0	1	3	7	31	
31	9	4	1	0	
+	—	+	—		

The error coefficients — 1/7 for the convergent 2/7 and + 4/3 for the convergent 1/3, can thus be obtained from the last three lines of the scheme; the error coefficients for other convergents are similarly obtained, so enabling the error associated with each convergent to be readily determined without the necessity of actually subtracting two fractions.

(*To be continued*)

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in practice a hollow body the internal surface of which has very good reflecting properties, with a small opening through which radiant energy is introduced, to the task of catching the sun's rays. A large parabolic mirror collects the rays and concentrates them in its focus, in which the orifice of the black body furnace is placed. Temperatures of up to 4000° K have thus been realized, permitting even thorium oxide and zirconium oxide to be melted almost instantaneously. It is hoped that the direct synthesis of nitric oxide, now performed in the electric arc, will also be realized in this way. The hot air engine recently revived in a high-efficiency form by Philips, will permit the heat energy thus made available to be converted into mechanical energy at a reasonable efficiency.

Practical difficulties arise from the sun's movement during the day, which must be followed eithe by the parabolic mirror itself or by intermediate plane mirrors (Heliostats). This latter arrangement has the advantage of permitting the parabolic mirror and the furnace to be fixed permanently. In order to enable the orifice of the black body furnace to be on the top, in the first set-up (by Mr. W. M. Cohn in Germany), the parabolic mirror was mounted with its axis vertical. In the set-up of the F.N.R.C. the parabolic mirror is mounted with its axis inclined to the vertical, a small intermediate plane mirror placed near the focus redirecting the rays into a vertical bundle forming the focus at the orifice on top of the furnace.

Fused alumina is expected to be the most suitable refractory material for the furnace, glucinium oxide for the crucibles.

Large-scale sun energy plants would consist of a large area of ground covered by heliostatic mirrors all reflecting the sun's rays into a parabolic mirror mounted on a tower of a height of 160 to 200 ft with the furnace below it.

Owing to losses by absorption by the atmosphere and in the reflecting apparatus, it is expected that about 50 per cent of the theoretically available radiant energy can be utilized.

THERMODYNAMICS

Introduction to the Comprex (Pressure Exchanger)

By F. W. BARRY. (From Paper No. 49-APM-18 presented to the *American Society of Mechanical Engineers* on June 13-15, 1949, 7 pages, 10 illustrations)

THIS paper describes the construction and operation of a comprex, or pressure exchanger, together with its application to a gas-turbine cycle. A simple analysis is also developed, which is intended to indicate the performance characteristics of a comprex. This analysis shows that the pressure ratio, relative gas flow, and the ratio of the temperature of the leaving gas to that of the entering air are all functions of scavenging velocity and of the nature of the compression and expansion processes. Some irreversibility is found to be essential to the useful operation of a comprex. Finally, formulae for the major dimensions of a comprex are presented.

WORKSHOP PRACTICE

Machining Stainless Steels

By LESTER F. SPENCER. (From *The Iron Age, U.S.A.*, Vol. 164, Nos. 1 and 4, July 7th and 28th, 1949, pp. 83-89 and 64-68, respectively, 8 illustrations.)

WHILE stainless steels can be machined without difficulty by using standard machine tools and tool material, variations necessary from practices recommended for machining carbon steels warrant close examination of specific machining jobs. Machining operations on martensitic, ferritic and austenitic stainless grades are analysed in this article by type of machining operation and machine tool. Also included is a description of the machining characteristics of various stainless steels, automatic screw machine tooling, tool data, and chip breakers and curlers.

Tapping and threading of stainless steels, including the various types of tools and methods of grinding them, skiving, shaving and other cutting operations are described. Several examples of tool set ups are shown, and tools and lubricants as they apply to machining stainless steel are discussed.

DESIGN TRENDS AND THE STYLE OF MACHINE TOOLS

Continued from page 30.

embodies three push buttons for "start," "stop," and "emergency return." The "start" button

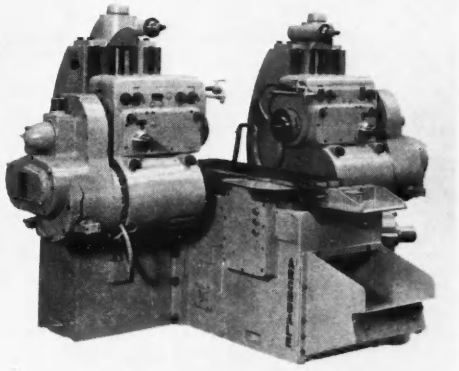

Fig. 92. **Archdale duplex milling machine.**

initiates the automatic cycle. "Stop" stops all motions at any point in the cycle. "Emergency return" returns the table to the starting position after using the "stop" button.

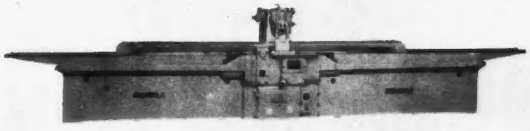

Fig. 93. **Archdale extended bed milling machine.**

Fig. 93 shows an Archdale machine similar to the above. It is of the push-button control type and has a specially extended bed for the milling of keyways in long shafts.

(*To be continued.*)

BIBLIOGRAPHY

(18) JAMES ANDERSON: Construction of a frame casing for a vertical lathe, from *Design for Welding* published in 1948 by the James F. Lincoln Arc Welding Foundation, Cleveland 1, Ohio, Chapter X, pp. 749-755.

(19) F. KOENIGSBERGER: *Design for Welding in Mechanical Engineering*, published in 1948 by Longmans, Green & Co., London, New York, Toronto.

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NEWS OF THE MONTH

PERSONAL

Mr. W. K. G. Allen, M.I.Mar.E., A.M.I.N.A., and **Mr. A. H. Chilton, M.I.Mech.E., M.I.E.E.,** have been elected, and **Mr. C. K. F. Hague, M.I.Mech.E., M.I.E.E., Sir Greville S. Maginnes, Mr. E. A. Robinson, M.C., M.I.Mech.E., M.I.Mar.E. Sir Basil R. G. Tangye, Bt., Mr. D. D. Walker, M.A., M.I.E.E.,** and **Mr. J. S. Woodrow** have been re-elected to the Council of the British Engineers' Association, 32 Victoria Street, London, S.W.1.

Mr. J. G. Barber, M.I.Mech.E., has been appointed London manager of Ruston and Hornsby Ltd.

Mr. Norman Elce, M.Sc.Tech., M.I.E.E., has been appointed chief mechanical engineer and director of Metropolitan-Vickers Electrical Co., Ltd., Trafford Park, Manchester 17.

Mr. A. E. C. Gregg, M.I.Mech.E., M.I.Mar.E., M.I.P.E., has been appointed managing director of Associated British Oil Engines (Marine) Ltd., Falcon Works, Loughborough.

Sir Walter Benton Jones, chairman of the United Steel Companies Ltd., 17 Westbourne Road, Sheffield 10, has relinquished his office of joint managing director of the Company. **Mr. Gerald Steel** has been appointed managing director, and **Mr. A. J. Peech,** deputy managing director. **Mr. K. G. Lampson** has become director of sales, and **Mr. H. M. Henderson,** general sales manager of the firm. **Mr. C. E. Edwards** has been appointed commercial manager of the Appleby-Frodingham Steel Company.

Mr. A. M. Lyon has been appointed general manager, and **Mr. A. S. Peacock** has been appointed assistant general manager of Babcock & Wilcox Ltd., Renfrew and Dumbarton works.

Mr. H. B. McAuslan has been appointed general sales manager, and **Mr. F. D. Langley, A.M.I.Mech.E.,** has been appointed London manager of the National Gas and Oil Engine Co., Ltd.

Mr. T. E. Parkinson has been appointed manager of the London Headquarters of the B.S.A. Tools Group. **Mr. R. N. Foyer** has been appointed continental representative for B.S.A. Tools Ltd., and The Index Automatic Machine Co., Ltd.

Mr. J. G. Scott has been appointed supplies manager of Electro-Hydraulics Ltd., Warrington.

Mr. E. C. Steer, B.Sc., M.I.C.E., M.I.W.E., is now a partner of Binnie, Deacon and Gourley, chartered civil engineers, Artillery House, Victoria Street, London, S.W.1.

Dr. R. J. Tudor, M.Sc., A.R.I.C., F.I.R.I., has been appointed director of the research laboratories of the British Tyre and Rubber Co., Ltd., Burton-on-Trent. **Mr. C. R. Cushman, A.I.R.I.,** has been appointed superintendent of the Silvertown works of the company.

Mr. L. Woodcock has been appointed sales manager of the industrial and marine units division of Leyland Motors Ltd.

BUSINESS NOTES

The Furnival Steel Co., Ltd., have now removed to Furnival Steel Works, Attercliffe Road, Sheffield 4.

Standard Telephones and Cables Limited (Newport Cables Division) announce the opening on January 23rd, 1950, of a new branch office and depot at 7/9 Tempest Hey, Liverpool 2 (Tel.: Central 0756). This additional branch, under the management of Mr. A. D. Fairless, will carry comprehensive stocks of Standard rubber and plastic cables.

The Gauge and Tool Makers' Association is contemplating the next Gauge and Tool Exhibition to be held at the New Hall, Vincent Square, London, S.W.1, in May, 1951, to coincide with the proposed Festival of Britain.

As at the two previous Exhibitions in January of 1946 and 1948, the products to be displayed will include gauges and measuring equipment, jigs and fixtures, special purpose machines, press tools, portable power tools, engineers' small tools, moulds and dies, and tools.

Economic Utilities Limited, Stone House, Bishopsgate, London, E.C.2, are the General Overseas Concessionaires for the **Walterisation Co., Ltd.** (Manufacturers of Rustproofing Processes). The Managing Director of Economic Utilities Ltd., Mr. H. J. Briess, is just completing a world business trip in order to promote Export for the Walterisation Co., Ltd., and has visited Canada, the United States, Australia, New Zealand, and is now on his way back to London, via the Far and Middle East. Mr. Briess has made valuable contacts with important industrial firms and Government Contractors. He succeeded in getting initial orders, for which quite a number of sample shipments have already gone abroad.

The Elcometer. With this pocket instrument developed by the East Lancashire Chemical Co., Ltd., Fairfield Road, Fairfield, Manchester, the thickness of a wide range of non-magnetic coatings, from paints, varnishes to tin plate, etc., can be measured to within ± 5 per cent. In addition, the thickness of non-magnetic sheet within the range of the instrument can be measured by putting it on top of a ferrous surface (tool-makers' flat, etc.). Checking is also easily carried out by a similar method using foil strips of a known thickness.

Since a permanent magnet is incorporated no connection to the electrical mains is neccessary and this renders the instrument portable as well as involving no running costs. The weight is only 6 oz. and, since the instrument is balanced in all planes, readings can be obtained in the most inaccessible positions. Measuremen is not confined to flat surfaces and practically any shapes execpt small bores and deep narrow pressings can be handled.

B.S.A. Tools Ltd., have acquired the goodwill, buildings and plant of Leo. C. Steinle Ltd., at 93 Albert Embankment, London, for the purpose of developing it as the Southern Headquarters of the B.S.A. Tools Group of Companies, comprising B.S.A. Tools Ltd., Burton, Griffiths & Co. Ltd., Index Automatic Machine Co. Ltd., and Leo. C. Steinle Ltd. The new London Headquarters will have facilities for the business accommodation and reception of overseas visitors and agents.

The Export Credits Guaramtee Department announces the opening of a new office at 14, Castle Street, Liverpool, 2 (Telephone No.: Central 7 56 7). Enquiries should be addressed to the Manager, Mr. E. J. Jackson, who will be pleased to discuss the Department's guarantees with interested exporters either at the above address or at their own offices.

Industrial Diamond Trade Names Index is a 48 pp. brochure containing the Trade Names, Firms, Addresses, etc., in this specialised industry. Publishers: N. A. G. Press Ltd., 226 Latymer Court, London, W.4. Price 3/6.

SUEZ POWER STATION EXTENSION

THE Suez Power Station which was recently brought into service and officially opened by His Excellency the Governor of Suez, Mohamed Bey Riad, has now been extended by the addition of new generating plant supplied by The General Electric Co. Ltd., of England.

The new plant consists of a 1,025 kVA, 3,000/3,300 volts, 375 r.p.m. G.E.C. alternator driven by a 1,250 h.p. supercharged "Mirrlees" Diesel engine.

The control boards, which embody switchgear, meters and relays also manufactured by the G.E.C., were erected and installed by the Egyptian agents of the company, the Tractor and Engineering Company, S.A.E., who were also responsible for the installation of the alternator.

This extension forms part of an extensive programme of post-war development undertaken by the Egyptian Government.

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BOOKS

Hydraulics and the Mechanics of Fluids. By E. H. Lewitt, B.Sc., Ph.D., M.Inst.Aero.E., A.M.I.Mech.E. Publishers: Sir Isaac Pitman & Sons, Ltd., Parker Street, Kingsway, London, W.C.2. 630 pp., 289 figures. PRICE 21/-.

The eighth edition of this well known book in the Engineering Degree Series contains a new chapter on Flow of Gases. Another useful enlargement is the Heat-Entropy chart for the solution of problems on air flow, orifices and nozzles, which is included into the book as a folding inset.

The work on the design of aerofoil blading has been rewritten and applied to water turbines of the propeller type and to the axial flow air compressor. New work has also been added on supersonic flow and on the frictional resistance of rough surfaces.

Steam Turbine Operation. By Professor William J. Kearton, D.Eng., M.I.Mech.E., M.I.N.A. Publishers: Sir Isaac Pitman & Sons, Ltd., Parker Street, Kingsway, London, W.C.2. 435 pp., 258 figures. PRICE 25/-.

The fifth edition of this excellent book dealing with the operating side of steam turbine engineering has just been published. Since 1931 when the first edition appeared engineers concerned with the installation, running and maintenance of steam turbines have derived much benefit from Professor Kearton's admirable and thoroughly practical treatise.

In this new edition, certain sections dealing with steam pipes and pipe joints, lubrication, governing, blade materials, blade deposits and feed heating, have been revised. New sections have been added on the installation and operation of the Brush-Ljungström turbine and on marine turbine emergency governors.

Principles of a New Energy Mechanics. By Dr. Jakob Mandelker. Publishers: Philosophical Library, 15 East 40th Street, New York 16, N.Y. 72 pp. PRICE $3.75.

Dr. Mandelker has evolved the new "energy mechanics" from the same basic relations as Einstein's special theory of relativity. The inertia mass conception has been replaced by the superior energy conception of matter; and in contra-distinction to Einstein's theory, this new mechanics considers the velocity of light c as a dependent, relative value, and restores the common conception of time as an independent quantity of everyday experience. The most significant result here is the new kinetic energy formula resolving all difficulties concerning the wave-corpuscular problem of matter as well as the question of the half-quantum.

Taschenbuch fuer den Maschinenbau. By Professor H. Dubbel. Publishers: Springer-Verlag, Reichpietschufer 20, Berlin, W.35 (British Section). Tenth Edition. Vol. I., 691 pp.; and Vol. II., 836 pp. 2,900 figures. PRICE DM28.50.

The publication of the tenth edition of Professor Dubbel's well-known excellent reference book will be welcomed by all German-speaking engineers and students who have been unable to procure a copy of the ninth edition published in 1943. Although certain sections on aeronautical subjects had to be omitted on instructions from the Allied Military Governments, the tenth edition is still a modern and up-to-date reference book of the greatest value to all mechanical engineers.

THE NEW MIRRLEES "J" TYPE RANGE OF HIGH PERFORMANCE OIL ENGINES

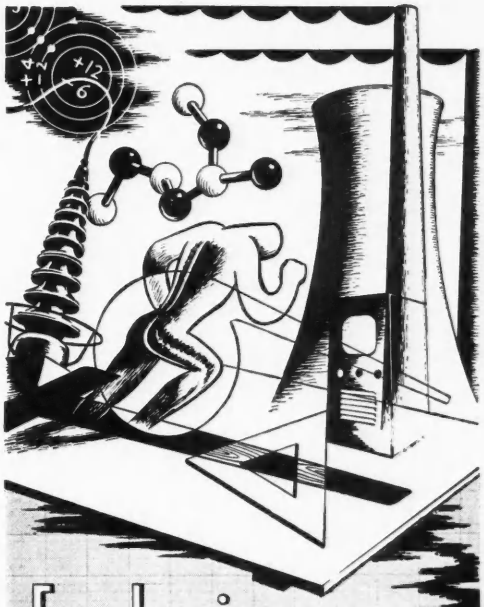
A THOROUGH market survey has shown the desirability of a basic engine for a wide range of duties involving special adaptations. These ideals required an engine of the same swept volume as the existing Mirrlees "TL" series, and in order to meet modern requirements of high powers, higher rotative speeds and low piston speeds, the bore and stroke were fixed at $9\frac{3}{4}'' \times 10\frac{1}{2}''$ respectively, allowing a speed range of 600 r.p.m. to 900 r.p.m. from six cylinders upwards, and a speed up to 750 r.p.m. for the 3, 4 and 5 cylinder "in-line" engines.

The new engine was required for Oilfield Drilling Rig applications; Marine Propulsion and Auxiliary Sets; Rail Traction Power Units; and as Industrial Stationary Engines.

By the design of a basic engine to cover these requirements, the engine could be manufactured at a reasonable cost by producing in large quantities. This would permit of the engine being sold for low and moderately high speeds, at conservative ratings giving large margins of powers, and also as high power weight ratio engines for rail traction and transportable units. The short stroke, large bore, permit of a very robust construction to withstand high pressures and high rotative speeds with very moderate piston speeds. With the four-valve head the engine is capable of giving high performance under normal aspiration, medium turbo-pressure charging and high turbo pressure charging with air cooler. The range will be built in 3, 4, 5, 6 and 8 cylinders "in line" and in 8, 12 and 16 cylinders in vee form. An exceptionally wide range of power will be available from 160 B.H.P. in 3 cylinders at 600 r.p.m. to 1,800 B.H.P. at 900 r.p.m. in 16 cylinders. The power ranges extend to cover 2,000 B.H.P. in high pressure charged form with air cooling.

In all sizes of engines the bedplate is in one piece and may be in cast iron or fabricated steel. In the initial design stage it was realised that both cast iron and steel construction would be required and provision was therefore made for manufacture of these components in either material. It is anticipated that three types of bedplate will be manufactured, i.e. Marine type, Traction and Transportable flat base type. The main bearings are steel shells W.M. lined and the locating bearing is gunmetal also W.M. lined.

The cylinder liners are chrome-hardened and are of the wet type. They have a continuous uninterrupted bore, there being no outaways for valve heads or connecting rod clearances.



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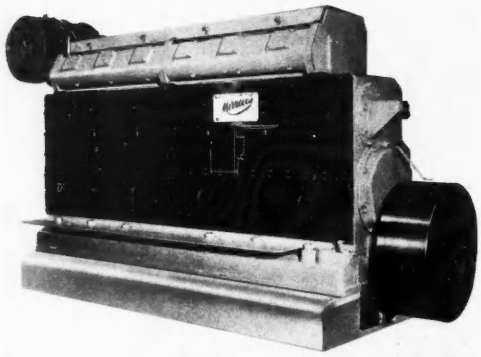

" JS6 " six-cylinder turbo-charged unit developing 800 B.H.P. at 900 rpm.

The pistons are of light alloy, and the combustion chamber is formed in the crown. Each piston carries a large diameter floating pin, three compression rings and two oil scraper rings of Mirrlees special design which effectively control the film of lubricating oil on the liner.

The connecting rods are of heavy "H" section, palm ended with marine type large-end bearings, consisting of steel stampings W.M. lined, and four large-end bearing bolts in high tensile steel. The small end bearing is a phosphor bronze bush.

The crankshaft is a 40/50 ton steel forging hardened and tempered to B.S.EN8. It has a flange at both ends, one to carry the flywheel and transmit the main drive, the other at the forward end permits the attachment of various types of extension shafts and T.V. Damper when necessary. The crankshafts are very stiff, there being a considerable overlap of pin diameter and journal diameter, thereby giving great strength across the webs. Two main bearings are provided at the flywheel end, the one nearest the flywheel being the locating bearing which also acts as a thrust bearing in the case of clutch applications, this bearing carries no firing pressure loads, but gives adequate support to overhung masses. At the forward end an extra bearing is fitted on the extension shaft when this is required to transmit drive to auxiliaries by means of pulley and belt, thus dispensing with the need of an outboard bearing, except in the case of exceptionally long extension shafts. In the case of "JV" crankshafts the pins are bored to reduce weight, but the oil supply ducts from the main bearings to the large ends are drilled through solid metal and no tubing is necessary, nor do the bored pins carry any lubricating oil. The crankshaft is provided with balance weights when occasion demands. The scantlings of crankshafts and connecting rods are above the dimensions required by Lloyds Register of Shipping for marine propulsion engines of high duty.

Gear drive is provided throughout for transmission to the various auxiliaries, camshaft, governor, oil pumps, water pumps, etc. The oil pumps and water pumps are fitted at the forward end of the engine, and the flexible drive for same is of the spring buffer type hydraulically damped. The camshaft is a continuous length of ground steel bar of heavy section carrying " howi-chrome " chill cast cam sleeves, and is supported in bronze bearings between each cylinder.

The governor is normally a centrifugal weight type, capable of mechanically hand controlled or hydraulically controlled, either by hand or, for special applications, by solenoids.

Much attention was given to the arrangement and design of the cylinder head and valve operating fear. The cylinder head is cast in close grain cylinder iron, it carries two exhaust valves, two inlet valves with separate inlet ducts, starting non-return valve, cylinder relief valve and indicator attachment. It is secured on the cylinder block by eight equally spaced high tensile studs of equal length. A copper gasket makes the gas joint between the cylinder head and the top of the cylinder liner. To provide efficient cooling, water is made to enter the under side of the head in the two corners adjacent the exhaust valves, here it is deflected by a horizontal division plate to the centre of the cylinder head, then the water is forced to flow past the injector, which is spaced centrally and the air valves and thence to the upper part of the water jacket. It leaves the cylinder head at the uppermost point on the exhaust valve side.

The valve operating gear consists of a forked exhaust valve lever mounted on a phosphor bronze bush which is clamped in a two-bearing bracket rigidly attached to the top of the cylinder head. Thus there is direct motion transmitted between the actuating push rod and the valves. There are no keys, bolts or spindles connected with this highly loaded mechanism. The more lightly loaded air valve levers are mounted on a splined shaft supported on the inside of the same bronze bush. All levers are fitted with adjustable tappets located in such a manner as to give line contact on the valve stems. The whole gear is pressure lubricated and totally enclosed by large hinged covers which give ready access to sprayers, valves, etc.

The turbo-blower is a standard type of machine and is mounted to suit customers' requirements either at the forward or flywheel end of the engine on a bracket which is bolted direct to the cylinder housing. On the higher pressure-charged engines, an air after cooler is fitted between the blower outlet and the engine induction manifold. This manifold is of particularly large capacity, thereby maintaining sufficient weight of air for all cylinders to become fully charged. The exhaust system on a naturally aspirated engine is normally of the water cooled type of manifold, and is equipped with expansion joints on 6 and 8 cylinder engines. This is replaced on radiator sets by an uncooled manifold to reduce the radiator capacity. The manifolds for the turbo-charged engines are of the mult-pipe type, arranged to give maximum efficiency of scavenging and to lead the hot gases to the turbine with a minimum of interference.

The engine is pressure lubricated throughout and is arranged for " dry " or " wet " sump alternatives. Pressure and scavenge pumps are located at a low level so that the suction is submerged in the case of "wet" sump engines. The scavenge pump is used on radiator cooled sets for circulating oil through the radiator at low pressure. In the case of marine auxiliaries the scavenge pump is duplicated so that oil may be drawn from each end of the sump, thus enabling the engine to run satisfactorily with a wide degree of list. The pump suction is protected by a box strainer inside the engine sump.

The standard lubricating oil filters are capable of handling full flow from the pressure pump and are of the self-cleaning type, but when conditions at site are severe, Duplex cloth type filters for lubricating and fuel oil are fitted. A standard make of oil cooler is supplied.

On naturally aspirated engines the standard air filters are of the rescious type and one is fitted at each end of the inlet manifold. For engines running under very arduous conditions large capacity oil-bath type filters are fitted.

The water pumps can be arranged as integral parts of the engine or, alternatively, proprietary makes of pumps may be belt driven from both ends of the crankshaft. Heat exchangers are strongly recommended.

Individual fuel pumps are situated in the " fuel chamber " above the engine camshafts, and are operated by roller tappets. The " fuel chamber " is formed in the cylinder housing and is so arranged that fuel leakage from sprayers, pipes and pumps is collected and drained externally so that there is no possible chance of dilution with the lubricating oil.

All "J" type engines are totally enclosed. There are absolutely no moving parts outside the covers and therefore no external hand lubrication whatsoever is required. The large covers provided permit of exceptional accessibility and when in place, give complete oil, water and dust tightness.

On all engines, pistons and connecting rods can be removed via the crankcase doors. On the " in line " engines they may be also removed through the cylinder when the heads are detached for valve inspection. On the " vee " engines the pistons and rods may be drawn upwards only if the cylinder liner is removed at the same time.

The cylinder heads which are in separate units form, together with the valve operating gear, very compact assemblies, and are relatively small and light for this size of engine.

The camshafts, decompressors shafts, fuel pump governor control shafts, etc., are all removed sideways via the camshaft covers and no provision is necessary in bulkheads, etc., for the withdrawal of long components. Main bearings may be inspected after removal of bearing caps with the crankshaft in position.

All main components, camshaft, governor, gear drive to camshaft, lubricating pumps, water pumps, flexible drive for pumps, engine control gear and valve operating gear, are arranged in sub-assemblies.

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